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WATER BALANCE AND SILTING OF SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM OF THE RUSSIAN SOVIET FEDERAL SOCIALIST REPUBLIC

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WATER BALANCE AND SILTING OF SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM OF THE RUSSIAN SOVIET FEDERAL SOCIALIST REPUBLIC

UNITED STATES DEPARTMENT OF AGRICULTURE

Agricultural Research Service

Soil and Water Conservation Research Division

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Laboratory of Limnology, Leningrad State University
Ministry of Higher and Secondary
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WATER BALANCE AND SILTING OF SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM OF THE RSFSR

Translated by
D. B. Krimgold, Hydraulic Engineer (Consultant)
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Professor S. V. Kalesnik

Editor of this issue

Doctor of Geographical Sciences

G. V. LOPATIN

Georgiy Vladimirovich Lopatin

(1898-1965)

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TRANSLATOR'S NOTES

In reading this translation it will be helpful to keep the following points in mind.

1. The transliteration system used was that of the U.S. Board of Geographic names (BGN).

2. To avoid errors and to reduce the cost of this translation some of the Cyrrilic alphabet subscripts and superscripts were left unchanged; they are, however, explained in the text and in footnotes.

3. Clarity and accuracy were given preference over strict rules of grammar, punctuation, consistency, etc. For instance, the season spring was spelled with a capital S to distinguish streamflow in the Spring of the year from the flow of a spring; surface water runoff rather than surface runoff was used to distinguish between sediment runoff and water runoff.

4. Names of reservoirs, rivers, provinces, and of authors are given the way they are pronounced. For instance, the name of the coauthor of one of the papers was transliterated Green as it would be pronounced in Russian rather than Grin as would be indicated by the BGN system of transliteration.

5. An attempt was made to eliminate repetitions and to shorten the very long sentences whenever possible. This, however, was scrupulously avoided when doing so would, in any way, change or distort the author's original intended meaning. Hence, the few unavoidable rough spots in the translation.

D. B. K.
December, 1966

FROM THE EDITORIAL BOARD

This collection of papers is dedicated to the bright memory of Doctor of Geographical Sciences, Georgiy Vladimirovich Lopatin, Senior Scientist of the Laboratory of Limnology, Leningrad State University, who edited the book when it was being prepared for publication. Notice of his death after a serious protracted illness was received when the volume was in galley proof.

The papers of this collection summarize some of the results of the expeditionary investigations of the Laboratory of Limnology, Academy of Sciences, USSR carried out in 1956-1961, as well as of the investigations of a number of other organizations, of the regime of small rivers and reservoirs of the Central Chernozem Provinces.

The first paper by G.V.Lopatin gives information on the number, sizes and principal uses of reservoirs of the Central Chernozem Provinces (CCP) and also some thoughts on the further development of this branch of the national economy.

The papers by I.P.Sukharev, A.M.Green and G.V.Nazarov, and by I.N.Sorokin discuss the forming of the regime of water runoff from small catchments (local runoff) under CCP conditions. The paper by I.N.Sorokin and also those by L.F.Forsh and I.Ya.Degopik deal with questions related to the elements of the water balance (in particular, evaporation) and with the hydrochemistry of small reservoirs in the CCP.

The papers of Ya.K.Kovalev, V.Ya.Frolov and L.V.Yakovleva are devoted to water erosion, river sediment load and sediment accumulation.

The three remaining papers (of G.V.Lopatin, M.Ya.Prytkova and of A.F.Kudryashev) present and give the basis of new methods of computing the rate of silting of reservoirs.

This volume is closely related to the previously published: "Hydrologic Regime of Small Reservoirs of the Kursk Province" (1961) and "Hydrologic Problems of the Uspenskoe Reservoir and of its Catchment" (1963) which contain results of investigations of small reservoirs in the CCP carried out by the expedition of the Laboratory of Limnology, Academy of Sciences USSR under the direction and with direct participation of G.V.Lopatin.

The "Agroclimatic Reference Books" for individual provinces of the RSFSR (Russian Soviet Federal Socialist Republic) used in this collection were for 1958-1959; the administrative subdivision of the provinces referred to in the papers are those of 1 January, 1958.

G. V. L O P A T I N

SMALL RESERVOIRS AND PONDS OF THE CENTRAL CHERNOZEM PROVINCES RSFSR

The construction and operation of small reservoirs (ponds) designed to meet various requirements of agriculture, industry and transport has been practiced in our country for a long time.

The great majority of the existing artificial reservoirs are small. Thus, for instance, in 1956 the kolkhoz (collective farm) reservoirs with surface areas less than 2 ha constituted 71% in the RSFSR and 52% in the Ukr. SSR.

According to 1956 data 40.7% of the existing kolkhoz ponds in the RSFSR were used for water supply, 10.7 for irrigation, 5.0 for fish culture, 1.0 for poultry, 8.5 for power, and 34.1% for a combination of municipal and manufacturing purposes.

However, the effectiveness and extent (completeness) of utilization of reservoirs for the indicated purposes were often quite low.

Information on the number of small reservoirs and of ponds of the Central Chernozem Provinces (CCP) of the RSFSR is given in Table 1.

Classification of Reservoirs

Artificial reservoirs can be grouped according to various characteristics: location in the hydrographic net; dimensions (capacity, surface area, depth); source of feeding; duration and extent of regulation of water runoff;

TABLE 1

Artificial Reservoirs of the Central-Chernozem Provinces (Ponds)

Ponds	Number of Ponds	Surface area, km^2	Volume thous. m^3	Water impounded by ponds, mm
Orel	1699	27.96	39377	2.04
Lipetsk	1322	25.47	48075	2.41
Tambov	729	55.50	66015	3.50
Kursk	376	30.73	53919	2.26
Belgorod	400	21.17	32000	1.46
Voronezh	1858	53.76	117459	3.50
Average	6384	214.29	356800	
			Average	2.0

R e m a r k. Data in the table are as of 1 Jan., 1956 assembled by I.P. Sukharev (1957)

type of utilization for the needs of the population and of the different branches of the national economy. Such a classification can be represented in the following form:

Classification of Artificial Reservoirs

1. By location in the drainage net
   - a) Lake,
   - b) River (channel and flood plain),
   - c) Ravine (in valleys of intermittent watercourses),
   - d) Slope (estuaries),
   - e) Pits and tanks.
2. By size (capacity, surface area, depth)

Reservoirs	Volume, $10^6 m^3$	Surface area km^2	Average depth m
Large	>1000	>100	>(6-10)
Average	20-1000	5-100	(4-5)-10
Small	1-20	(0.3-0.4)-5	(1-2)-(4-5)
Ponds	<1.0	<(0.3-0.4)	<(1-3)

3. By source of feeding
   - a) Atmospheric feeding (snow and rain),
   - b) Atmospheric-ground feeding,
   - c) Ground feeding
   - d) Artificial feeding (filling).
4. By degree of regulation
   - a) Complete regulation (long-term and annual),
   - b) Partial (incomplete) regulation (seasonal, monthly, etc.).

5. By utilization of the reservoir for the needs of the national economy.

a) Water supply (for inhabited points, industrial plants and others),

b) Irrigation (fields, orchards, gardens),

c) Fish culture,

d) Poultry,

e) Hydropower,

f) Combined utilization,

g) Beautification, sport and health purposes,

h) Fire fighting.

As an example basic data applicable to the proposed classification for some existing reservoirs are given in Table 2.

TABLE 2

INFORMATION ON SOME EXISTING RESERVOIRS

Reservoir	Category	Volume $10^6 m^3$	Surface area, km^2	Average depth, m
Rybinskoe.	Large.	25420	4550	5.6
Tsimlyanskoe.	"	23800	2600	9.2
Kutulukskoe.	Medium.	105	22	5.2
Syzranskoe.	"	30.7	7.9	3.9
Domashkinskoe.	"	20.0	5.53	3.9
Karlovskoe.	"	25.0	6.2	4.0
Uspenskoe.	Small.	2.4—2.6	0.7—0.8	3.4
Borshchenskoe.	Pond.	0.76	0.35	2.1
Nelidovskoe.	"	0.044	0.05	0.9

The possibility of grouping reservoirs according to other characteristics: overgrowing, silting, salinization, bioproductivity, etc. is not excluded.

Effectiveness of Utilization of Small Reservoirs (Ponds) in the National Economy

I r r i g a t i o n. Experience with irrigation on the fields of the Dokuchaev (Kamennaya Steppe) Agricultural Institute of the CCP and of a number of leading collective farms of the Voronezh Province shows that with average agrotechnics but with timely and proper irrigation the yields of vegetables, sugar beets, and of corn are substantially increased (Sukharev, 1957). For instance:

Vegetables (cucumbers, cabbage, tomatoes)	2-3 fold
Sugar beets	2-fold
Corn (sillage)	3-fold
" (grain)	2-fold plus.

Irrigation of fruit orchards is highly effective.

F i s h c u l t u r e. The catch of fish in specialized reservoirs usually amounts to 10 to 20 ct./ha. of water surface. With proper organization of production this quantity can be further increased.

The Tarashchinskie ponds in the Kiev Province which supply fresh fish and a considerable income to a number of kolkhozs are well known.

The value of pond fisheries consists principally in the local consumption of fish by the rural population since the shipping of fish caught in large water bodies (in the seas) to rural localities is quite difficult.

Large enterprises are now being planned and undertaken for the increase of the catch of fish and for the production of fishery products. State hatcheries will be built to stock the kolkhoz and sovkhoz (state farm) ponds which will aid in the further development of pond fisheries (Ishkov,1963).

P o u l t r y p r o d u c t i o n. The raising of water foul on ponds is also gradually increasing. In the Ukraine a number of farms produce in addition to fish 30-50 kg of duck meat per hectar of water surface of these reservoirs.

Experience in raising ducks in the Priozerskiy District of the Leningrad Province shows that in 62-63 days of feeding, a duck can attain an average live weight of 1.8-1.9 kg. It is therefore possible to feed out up to 2-3 flocks of ducks during a summer season.

These, however, are only single cases. The situation with respect to raising water foul is particularly unsatisfactory. We have many districts and provinces with excellent conditions for raising ducks and geese. However, very little is done in raising of water foul in these areas.

L i v e s t o c k p r o d u c t i o n. It is quite difficult to give a quantitative evaluation of the effectiveness of utilization of reservoirs in livestock production (without special economic calculations). It is, however, generally known that in a number of cases in the steppe and forest-steppe provinces ponds are the only means of watering cattle on pasture.

O t h e r b r a n c h e s o f t h e n a t i o n a l e c o n o m y. It should be noted that with continuous exploitation of fish and water foul reservoirs the quality of the silt and of the water are gradually impaired, which affects the productivity of such reservoirs. The so-called summering when, in a given year, the bottoms of emptied ponds are used to raise forage grasses, vegetables, milo, sugar beets, etc. is a good means of quick mineralization and reclamation of a pond. Under such conditions yields of up to 500 ct. of beets per hectar are obtained.

There are now already sufficiently substantial analysis of the raising of useful plants in the shallow parts of ponds and reservoirs which can give additional supplies of forage, for instance, Canadian and Far Eastern rice and others has already been sufficiently well worked out. It is known that perennial wild rice gives from 300 to 700 ct. of sillage for each hectar of surface and that Canadian rice gives in addition also large amounts of grain (Pritchin,1963).

One must also note the considerable accumulation in the reservoirs and ponds of ooze deposits which are often good fertilizer. These deposits contain 52% of phosphorus, 21.16% of nitrogen, and 0.9% of potassium.

It should be noted that reservoirs and ponds are not only useful to individual branches of the national economy but are also of general importance in creating conditions for more successful development of a number of branches of the national economy especially in the zone of insufficient moisture. Reservoirs regulate surface runoff, reduce

discharges of water of Spring and rain floods, convert part of the surface runoff into underground runoff which notably increases soil moisture and improved the climatic conditions of the locality.

Thus, for instance, according to observations in the Voronezh Province (Kamennaya Steppe), humidity in the summer in the vicinity of the reservoir on the Talovaya Ravine at a distance of 1-1.2 km from the banks of the reservoirs is 8-12% higher than on the area to which the influence of the reservoirs does not extent (Sukharev,1957).

With an increase in the number of reservoirs the regulation of water runoff increases i.e., the effectiveness of the influence of reservoirs on the regime of surface runoff and therefore also on the moisture supply of the area, on the rates of water erosion and on the river sediment load.

Even now, with a relatively small number of reservoirs the regulation of water runoff locally reaches substantial dimensions.

According to O.N.Borsuk (1958) ponds and reservoirs have practically no effect on the annual runoff in the north and in the middle belt of the European part of the USSR. Not only during average years, but also in dry years the diversion of water from the natural flow of small rivers does not exceed 1%. The southern boundary of this region lies to the west of the mountain and foothill districts of the Carpathians, it then turns eastward, crosses the lower reaches of the Pripyat' River, passes along the

Seym River, goes on to the City of Voronezh and then veers somewhat to the north; it crosses the Volga River above Kuybyshev and the Ural Mountain range in the vicinity of Sverdlovsk.

To the south of this line a decrease in annual runoff becomes noticeable reaching 10-15% in an average year. In dry years the diversion of the natural flow on the Volyno-Podol'sk Highland and in the southern part of the Mid-Russian Highland reaches 20-30% on individual rivers. The annual flow is distorted to the greatest extent in the Cis-Black Sea depression (up to 50-60%), in the steppes of the Northern Caucasus (60-70%) and in the Cis-Caspian Depression where in exceptionally dry years some river channels remain dry during the entire year.

The regulation of maximum discharges of the Spring high water of usual design frequencies are of no practical importance for the greater part of the European territory. North of the line defining regions of unregulated annual flow, the reduction of maximum discharges of high water apparently does not exceed 1-5%; in wet years it is not greater than 2-3%.

In more southerly districts the regulation of Spring high water by reservoirs increases and on some small rivers it becomes noticeable. The reduction of maximum discharges for average high water constitutes 5-10% on many rivers. In individual cases, it is 10-20%. Reservoirs on individual

small rivers reduce the maximum discharges with a frequency of 1% by 5-10%.

All the abovesaid forces us to admit that the construction and operation of small reservoirs and ponds are an important branch of the national economy which is related directly to measures for increasing agricultural production, to the meeting of essential water requirements of industry and of the population and in addition, exerts an important influence on climatic conditions of the locality and therefore on the general conditions of agriculture.

Present Status of Small Reservoirs and Ponds in the Steppe and Forest Steppe Zones

The status of small reservoirs and ponds in the steppe and forest steppe zones, i.e., where they are particularly needed, must be considered quite unsatisfactory.

The basis for such a statement are the data of investigations of these reservoirs carried out in the last twenty years and possibly even the last thirty years. Such data were obtained in particular, in the investigation of the Voronezh Agricultural Institute in the Voronezh Province in 1927 (A.D. Dubakh); the Institute of Hydrology and Hydrotechnics Academy of Sciences Ukr. SSR in the Ukraine in 1937-1939 and 1958-1960 (N.I.Drozd and M.V.Myalkovskiy); the Regional Land Office and the Nizhnevolgoproekt in the Povolzh'e in 1928-1932 and in 1934-1953 (I.A.Kuznik and B.V.Polyakov); Sevkavvodproekt in the Stavropol' region in 1938 (S.S.Mikhalchenkov); Lengiprovodkhoz in the Belgorod Province and in the southern Trans-Volga in 1948

and 1951-1953 (file data); of the State Hydrologic Institute in the Moldavian SSR and in southern Ukraine in 1953-1954 (O.N.Borsuk, M.Ya.Prytkova and others); the Dokuchaev Central Chernozem Belt (CCB) Agricultural Institute in the Voronezh Province in 1953 and later (I.P.Sukharev); the Kazan' branch of the Acad. of Sci. USSR in the Orenburg Province and in other provinces of Povolzh'e in 1953-1954 (G.N.Petrov); Agrolesoproekt in the Rostov, Volgograd and other provinces in 1952-1953 and later (Nikolaenko, 1961); Laboratory of Limnology Acad. of Sci. USSR in the Rostov and Volgograd Provinces in 1949-1954 (under the direction of A.B.Shnitnikov); and in the Kursk, Orel, and Voronezh Provinces in 1956-1961 (under the direction of G.V.Lopatin).

The same evaluation of small reservoirs was given by two interdepartmental conferences on small reservoirs (in 1957 and 1959) organized by the Laboratory of Limnology, Academy of Sciences USSR and was appropriately reflected in the resolutions of these conferences.

The principal causes of the poor state of reservoirs include: defects in planning and construction of spillways, poor maintenance and delayed repairs of dams and spillways, defects in operation, silting processes and overgrowing and pollution of reservoirs.

Let us briefly consider the effects of these causes.

Defects in planning and construction. Until recently the construction of small reservoirs was sporadic by recurrent campaigns.

Thus, for instance, it is known that particularly rapid construction of small reservoirs took place in 1892-1893 (immediately after the dry and famine year 1891), in 1925-1926 after the dry year 1923, and finally in 1949-1953 (in connection with the famous decree of the government of the USSR in 1948 on means of raising the productivity of agriculture).

It is quite understandable that the hurried conduct of the recurrent campaigns of construction of small reservoirs did not make possible a sufficiently correct and rational selection of reservoir sites, the conduct of the necessary complex of studies for the planning and the control of the quality of construction.

The negative results of such a hurry were not long in showing up.

Thus, for instance, A.Dubakh (1928) reports that of the total number of dams constructed in 1892, 33% were breached already in the following year of 1893. A considerable number of dams built in 1949-1952 broke through already in 1950-1954 as was shown by A.V.Shnitnikov in his paper (1957).

In 1956-1960 the writer inspected reservoirs constructed in 1951-1953 in the CCP. Many of these dams were in very poor condition already in 1956, some of them broke through in the wet year 1960.

The insufficient consideration of the purpose of the reservoirs that were being built and their failure to meet the needs of the local population should also be noted.

Thus, for instance, the construction of reservoirs in the Kursk, Orel and Belgorod Provinces intended to insure yields of grain crops failed completely. Poor irrigation practices, cumbersome stationary pumping installations, frequent changes (rotation) of agricultural crops - all this nullified to a great extent the value of these reservoirs in the irrigation of not only grain but also of other agricultural crops.

P o o r m a i n t e n a n c e a n d d e l a y e d r e p a i r s. The washing out and breakthrough of spillways occur as a rule, during the Spring high water. Experience of operation shows that cleaning of snow and ice in the spillway channels is done largely at the wrong time and improperly. This causes washing out (or breakthrough) of the spillway channel, the repair of which is usually not completed before the high water of the following year. Washing out and destruction therefore increase from year to year until the pond washes out in one of the wet Springs.

In individual cases spillway structures fail as a result of incorrect calculations such as, for instance, of the maximum discharge and the poor construction of concrete in the chutes of the spillway channel and in the stilling basins.

All the causes of these shortcomings should have been disclosed on the spot by special commissions immediately after the flood in order that they may be taken into account

in future planning and construction. However, such inspections were either not made at all or were made by quite unqualified and often dishonest personnel.

To bring order into this business it is necessary to increase the responsibility of the planning and construction agencies for the maintenance of the structures at least during the first two years after the end of construction (a guarantee period). It is also necessary that the repairs be made quickly i.e., in the same year when the damage occurs.

Defects of systems of operation. The principal defects of operation of small reservoirs must be considered the lack (in the majority of cases) of a person responsible for the operation of the reservoir. On the kolkhoz reservoirs there is usually no responsible person at all, in cases where such people are appointed they actually lack the means of doing anything to improve the conditions of the reservoir.

In individual cases reservoirs are found which are utilized for fish and poultry production and bring in a definite income to the members of the kolkhoz. These reservoirs are cared for and have a definite "guardian" and therefore are in relatively good condition. There are, however, very few such reservoirs.

It is necessary to note another group of reservoirs (aside from kolkhoz) which are small in size and are the responsibility of state organizations. Their care and repairs are carried out by the facilities of special

offices (administrations) of the irrigation network which operate within the boundaries of several administrative districts of a province. On such reservoirs there existed in the past (up to 1957) a special staff of workers: a technician - meliorator, pumping station mechanics (one or two), and a watchman. Such reservoirs were in relatively good condition. However, in connection with the poor utilization of these reservoirs in the national economy the servicing personnel was gradually reduced and in 1959-1960 reached its lowest mark, i.e., only one man (a mechanic or a watchman). For this reason the condition of these reservoirs (dams and spillways) begin to deteriorate considerably.

In talking of the operation of small reservoirs one must also discuss the completeness of their utilization and the technical means which must be applied in different cases of operation.

In a very large number of cases the existing small reservoirs are utilized to a very limited extent because they were either not suited to the particular type of operation to start with or because the agency which operated the reservoirs was unable to organize its rational utilization.

We shall give a few examples.

A large number of reservoirs was built without a bottom outlet and therefore could not be emptied annually for the purpose of catching the fish. Such reservoirs could therefore not be utilized for fish culture.

Almost none of the reservoirs have stock watering devices. The cattle come to the water's edge and even enter the water with the result that the banks of the reservoir are systematically destroyed which leads to accelerated silting of the reservoirs and to serious pollution.

On small reservoirs of the Kursk and Belgorod Provinces diversions for irrigation were usually built at a definite point for pumping the water into a tank the location and height of which made it possible to irrigate a relatively small area. It is preferable to install a portable pumping installation (maybe even floating ones) which could deliver water to several previously selected control points. This would considerably expand the irrigation of fields. In connection with crop rotations a part of the fields adjoining the reservoir are during some years excluded from the annually irrigated area (for instance, fallow, grain). It would therefore be advisable to exclude from the common crop rotation the land adjoining the reservoir and to use them continually for vegetables or orchards and also for such crops that require irrigation every year. Then the utilization of the reservoir for irrigation would be continuous and complete.

The overgrowing of shallow reservoirs by weeds takes place spontaneously yet it is quite possible to grow a number of plants which are of considerable value (for instance, Canadian and Far Eastern rice and others).

Water bodies in the CCP are silting rapidly. It is therefore necessary to apply a set of measures in combating

water erosion on the catchment and in retaining the products of water erosion (sediment) at the approach to the reservoir (by planting shrubs). The products of water erosion accumulating near the reservoir can be utilized as fertilizer. A definite amount of the brush vegetation can be utilized as construction material (fences, barn roofs, etc.) and as material for various articles of consumption.

In cases where a substantial part of the tributaries of a river has already been utilized for the construction of small reservoirs and ponds and the Spring and summer discharges of the river were thereby considerably reduced, there arises the possibility of a more complete and systematic utilization of the flood plains of this river system in agriculture not only for hay but also for irrigated crops (gardens, fields, etc.).

The methods of evaluation of small reservoirs and ponds and the inspection of their conditions were not sufficiently satisfactory in the past. It is for this reason that the data on evaluation of ponds reported by a number of authors for individual periods do not always agree. In 1950-1956 the organization of this activity was considerably improved. In 1957 the Ministry of Water Economy of the RSFSR was abolished. Then the Provincial Administrations of Water Economy were liquidated. The Divisions of Water Economy in the Provincial Administration of Agriculture which took the place of the liquidated administrations were also soon abolished and in 1959-1960 all that remained were the files

and 1-2 water economy workers (meliorators) for an entire province. The offices of the administrations of the irrigation systems also completely disintegrated.

For this reason it was almost impossible to obtain in 1960 information on the number of operating artificial reservoirs in the CCP and on their conditions in individual provinces. Yet the condition of these reservoirs was substantially impaired because of insufficient maintenance.

The experience in the inspection of small reservoirs in the CCP in 1956-1960 indicates the advisability of recommending a number of measures for the improvement of the construction and operation of small reservoirs such as the following:

1. To develop basin programs of multi-purpose utilization of local runoff. In the past it was the practice to plan and build individual reservoirs on requests of some industrial organizations, agricultural cooperatives or even on general considerations of the planning organization. It now appears advisable to change to a practice of planning systems of reservoirs within individual catchments. It is desirable and even necessary to implement as an experiment (planning and construction) several such systems of reservoirs taking into account, of course, the need for them in the national economy.

2. To develop and improve methods of hydrologic and hydrogeological calculations in determining various characteristics of runoff and water losses which are needed

as a basis for planning a reservoir. Needed in particular, are recommendations for the computation of probability of maximum water discharges.

It should be noted that design methods were developed primarily for large and medium rivers. For small rivers by far not all the methods have been developed and tested to a sufficient extent.

3. To develop recommendations for the selection of types of reservoirs suitable for specific conditions, (for instance, with complete or only partial retention of flood flows).

There is substantial disagreement among specialists about the advantages of various types of small reservoirs. Apparently, this problem must be solved keeping in mind natural conditions and the purposes of the reservoirs.

4. To develop recommendations for the selection of types and sizes of spillways (pipe, open and others). Types of spillways are well worked out but their selection must be made considering local natural conditions. It is also necessary to improve the system of inspection of proper implementation of construction of spillways because the quality of constructed spillways often leaves much to be desired.

5. To develop methods of computation of possible silting of reservoirs and also recommendations for the protection against silting.

It should be noted that methods of calculation of possible silting of reservoirs and recommendations on the protection of water bodies against silting are now more or less worked out. However, the entire complex of measures of protection against silting remains almost unused in practice. It is obvious that special regulations of governmental organizations are needed.

6. To develop recommendations on rational operation of reservoirs taking into account the objectives and local natural conditions.

A large amount of work is yet to be done on this problem since more specific instructions are needed in addition to general declarations.

7. To hold the planning and construction organization responsible for the quality of construction of reservoirs and the operating organization for the maintenance of all the links of a water economy unit. This is of great importance and can be accomplished only by a special governmental decree.

In concluding we shall formulate the principal tasks in the further study of the problem of small reservoirs and ponds as problems of multi-purpose utilization of local runoff for various branches of the national economy.

1. Continuation of systematic information and discussions of the most pressing problems of small reservoirs at interdepartmental conferences similar to those held in 1957 and 1959 by the Laboratory of Limnology Acad. of Sci. USSR (Proceedings of these conferences were published in 1958 and 1961).

2. Creation of several scientific research stations on small reservoirs in different geographical zones for carrying out systematic observations over a period of years on the entire complex of phenomena and processes arising in these reservoirs. The obtained data will aid in the development of hydrologic calculations in the planning of reservoirs.

Methods, instruments and installations to be used in field investigations connected with the construction and operation of reservoirs can also be tested and verified at these stations.

3. A considerable expansion of the hydrometeorological Service, USSR on small rivers including also runoff stations aimed at obtaining factual data for determining the peculiarities of the hydrologic regime of small rivers under different natural conditions (this was included in the resolution of the second interdepartmental conference on small reservoirs held in 1959).

The plans for the location of new stations of the Main Administration of the Hydrometeorological Service on small rivers within the boundaries of RSFSR should be coordinated with the Committee on the Water Economy (Goszemvodkhoz) of the Council of Ministers of the RSFSR.

4. To introduce into the practice of planning organizations the checking of data used in the planning of small reservoirs by carrying out special observations on reservoirs after they are constructed.

5. To strengthen the work of scientific research organizations of appropriate agencies in the study of utilization of local runoff by construction and operation of small reservoirs and ponds.

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I. P. SUKHAREV

LOCAL RUNOFF OF THE CENTRAL CHERNOZEM PROVINCES

In connection with the development of irrigation and pond construction, a number of organizations carried out (mainly in 1933) investigations of local runoff in these provinces as well as of some factors affecting its magnitude and regime.

Important work in this field was done by the Dokuchaev (Kamennaya Steppe) Central Chernozem Belt (CCB) Agricultural Institute with the participation and under the direction of the author of this paper.

The paper discusses the data on runoff from small catchments in the Voronezh and Kursk Provinces and data from small runoff plots and small catchments on the effects of the following factors on the magnitude and regime of local runoff: ice crust, winter precipitation and agricultural activities of Man.

Runoff from Small Catchments in the Kamennaya Steppe District of the Voronezh Province

Investigations of surface runoff at Kamennaya Steppe were conducted both on the land of the Dokuchaev Agricultural Institute and on the land of the adjoining kolkhozs of the Talovskiy District. The longest observations were carried out on the catchments of the following ravines: Ozerki, Krasnaya, Osinovaya, Lesnaya, Stepnaya and Selektsentrovskaya. Shorter observations were made on the catchments of the

Khorol'skaya (Vill. Khorol'skiy), Kamenka (Vill. Stanitsa Dybov and Novaya Kamenka), Dubovaya (Vill. Bogatyr'), Berezovaya, and Sukhaya Chigla Ravines. On the first six catchments observations were made during 15-24 years; on the remaining during the last 6-8 years, beginning in 1950.

Some of the information on the above-enumerated Kamennaya Steppe catchments is given in Table 1. The areas of the steppe catchments range from 2.1 to 140 km^2, the slopes of these catchments are different. The first four catchments (Ozerki Ravine, Headwaters of Ozerki Ravine, and the Selektsentrovskaya and Lesnaya Ravines) have forest belts. A comparison of runoff from the steppe catchments with that from forested ones makes it possible to reveal the effect of afforestation on runoff of snowmelt and of intense rain water. The soils of the catchments are represented by chernozem 0.5-0.6 m thick underlain by clay loam.

Values of runoff and of coefficients of runoff for each catchment are given below.

The catchment of the Ozerki Ravine is the oldest of the Kamennaya Steppe experimental catchments. Observations of surface runoff on this catchment began by the B.V.Dokuchaev Expedition in 1893 and continued over three subsequent years. The observations were then discontinued and were resumed only in 1935 (by the Kamennaya Steppe Reclamation Station).

Plowing of the catchment of the Ozerki Ravine began in 1922-1923; thus, up to 1922 it remained under natural conditions (a steppe catchment).

TABLE 1

CHARACTERISTICS OF THE KAMENNAYA STEPPE EXPERIMENTAL CATCHMENTS

Ravine	Catchment area, F km^2	Slope along the rav. axis J	Average slope of the catchment $J_{av.}$	Dimensions of the catchment, km			Completeness coeff. of the catchment	Year of beginning of observations of runoff	Forest cover,%
				Length	Average width	Greatest width			
Ozerki	26.5	0.0071	0.0152	9.1	1.26	3.85	0.32	1935	3.6
Headwaters of Ozerki rav. . . .	7.1	0.0079	0.009	3.2	0.73	2.2	0.78	1950	9
Selektsentrovskaya	0.72	0.0063	0.0106	1.5	0.18	0.70	0.32	1938	18
Lesnaya	1.75	0.0105	0.0167	2.2	0.32	1.0	0.36	1934	6
Stepnaya	2.10	0.007	0.013	2.0	0.37	1.2	0.47	1934	0
Osinovaya	24.7	0.008	0.018	10.1	1.0	3.6	0.24	1935	0
Krasnaya	18.0	0.0077	0.019	9.9	0.86	3.2	0.18	1935	0
Talovaya	90.0	0.001	0.015	12.7	2.43	8.6	0.56	1951	0
Khorol'skaya . . .	17.5	0.005	0.008	5.7	1.0	4.0	0.54	1951	0
Kamenka	15.6	0.0055	0.008	5.0	1.04	4.0	0.62	1951	0
Kamenka	35.0	0.003	0.010	12.8	1.15	4.0	0.21	1950	0
Dubovaya	7.0	0.005	0.009	3.5	0.63	2.7	0.57	1951	0
Berezovaya	113.0	0.0025	—	—	—	—	—	1951	0
Sukhaya Chigla . .	140.0	0.001	—	12.7	—	13.5	0.88	1951	0

In order to compare surface runoff under different conditions, years were selected which were similar with respect to meteorological conditions in the fall, winter, and during the period of snow melting, namely 1893-1895 and 1950-1958.

A comparison of the data for these periods showed that surface runoff under natural conditions was considerably greater than on the plowed catchment.

Data on runoff from the catchment of the Ozerki Ravine (the mouth, middle and upper gaging sections) obtained by the Dokuchaev Expedition for 1893, 1894 and 1895 and those for 1950-1958 are given in Tables 2 and 3 respectively.

Water equivalent of snow on the catchment was taken from the data of the meteorological station (winter precipitation), therefore the runoff coefficient was computed by dividing the runoff by the amount of winter precipitation.

It should be noted that in the winters of 1892/1893 and 1893/1894 there were frequent thaws during which the snow partially melted. Ice crusts formed on the surface of the soil increased runoff.

The winter 1894/95 was also interrupted by a number of thaws: 5-12 January and 20-22 February. During these days winter floods were observed. V.I.Deych (1898) wrote in the transactions of the expedition: "High water started much earlier and exceeded every expectation in the month of January; on the night of the 12-13th a heavy rain fell over Kamennaya Steppe; the water runoff over frozen ground quickly filled the pond and flowed through all the spillways."

The thaw of the 20th to the 22nd of February also caused snow melting and runoff on the catchments. The next Spring flood passed between the 13 and 15 of March.

Such a characteristic of the winter was undoubtedly conducive to an increased value of the runoff coefficient on the catchment.

In 1950 the author measured the runoff in the headwaters of the Ozerki Ravine a little above the end of Rogatyy Pond. The measurements were made with a rectangular broad-crested weir. The area of this catchment was 7 km^2.

Spring runoff data for the catchment of the headwaters of the Ozerki Ravine are given in Table 3.

Table 3 shows that in 1950-1958 the runoff on the catchment of the headwaters of the Ozerki Ravine was much smaller than that on the unplowed catchment (1893-1895). The reason for such a sharp reduction in runoff is Man's agricultural activity (plowing of the catchments, introduction of correct crop rotations, afforestation of the catchment, and construction of ponds).

Information on the Spring water equivalent of snow, on runoff, and on runoff coefficients for the forested catchments of the Ozerki, Selektsentrovskaya and Lesnaya Ravines and also for the steppe catchments of the Stepnaya and Osinovaya Ravines for 1933-1957 is given in Table 4.

This table shows that the water equivalent of the snow and the runoff from the forested and steppe catchments change greatly both from year to year and with the degree of afforestation.

TABLE 2

RUNOFF FROM THE CATCHMENT OF THE OZERKI RAVINE FOR 1893-1895

Catchment	Catchment area, km^2	1893		1894		1895	
		Runoff, mm	Runoff coeff.	Runoff, mm	Runoff coeff.	Runoff, mm	Runoff coeff.
Mouth of Ozerki rav.	26.58	—	—	55.7	0.86	—	—
Middle of Ozerki rav. at N. Rogatnyy Pond	9.82	35.8	0.51	53.8	0.87	10.0	0.82
Headwaters Ozerki rav.	4.15	—	—	—	—	8.3	0.68

TABLE 3

RUNOFF FROM THE CATCHMENT IN THE HEADWATERS OF THE OZERKI RAVINE

Item	1950	1951	1952	1953	1954	1955	1956	1957	1958	9-year average
Spring water equiv. of snow, mm	50.0	60.0	45.0	115.0	45.0	40.0	45.0	32.0	38.0	52.2
Runoff, mm	4.4	24.0	14.0	35.0	1.2	12.0	6.5	3.5	4.0	11.6
Runoff coefficient	0.08	0.40	0.24	0.31	0.03	0.76	0.16	0.11	0.10	0.21

TABLE 4

INFORMATION ON WATER EQUIVALENT OF SNOW (P,mm), RUNOFF (C,mm) AND RUNOFF COEFFICIENTS (K) ON THE CATCHMENTS OF THE OZERKI, SELEKTSENTROVSKAYA, LESNAYA, STEPNAYA, AND OSINOVAYA RAVINES FOR 1933-1958

	Ozerki			Selektsentrov-skaya			Lesnaya			Stepnaya			Osinovaya		
	P	C	K	P	C	K	P	C	K	P	C	K	P	C	K
1933	—	—	—	—	—	—	112.8	49.6	0.44	94.2	65.0	0.69	—	—	—
1934	—	—	—	—	—	—	113.2	26.2	0.23	133.2	35.0	0.26	—	—	—
1935	59.0	6.6	0.11	—	—	—	79.8	5.5	0.07	67.1	11.5	0.17	61.6	7.2	0.11
1936	43.4	27.0	0.62	—	—	—	77.2	34.7	0.47	55.2	42.7	0.77	49.0	45.7	0.93
1937	55.1	16.3	0.30	—	—	—	102.9	30.8	0.30	54.6	24.0	0.44	59.1	26.3	0.45
1938	58.0	42.2	0.73	124.6	0.5	0.003	90.8	28.4	0.31	88.0	41.5	0.47	74.7	71.4	0.95
1939	44.8	20.2	0.45	120.0	0.8	0.007	55.0	19.8	0.36	42.0	24.2	0.57	62.8	25.5	0.60
1940	128.0	40.5	0.31	132.0	7.1	0.054	130.0	53.0	0.41	74.0	61.0	0.82	123.8	99.0	0.80
1941	95.3	69.2	0.73	140.0	28.1	0.20	126.0	87.0	0.69	117.4	103.0	0.88	121.0	112.0	0.91
1942	127.7	77.3	0.61	173.0	45.6	0.26	—	—	—	—	—	—	131.8	120.0	0.91
1943	145.4	30.6	0.21	154.4	0.0	0.0	167.4	26.4	0.16	—	—	—	152.5	35.6	0.23
1944	45.9	4.8	0.10	47.9	0.0	0.0	50.9	2.3	0.04	—	—	—	45.9	9.8	0.21
1945	117.2	17.6	0.15	145.0	2.8	0.02	102.0	18.3	0.18	—	—	—	97.0	35.0	0.36
1946	101.1	42.5	0.42	94.0	36.6	0.39	91.0	30.0	0.33	—	—	—	83.7	56.7	0.68
1947	91.0	47.0	0.52	126.1	39.3	0.30	80.1	38.0	0.47	—	—	—	72.5	56.8	0.78
1948	87.5	61.3	0.70	118.0	40.5	0.34	84.8	53.4	0.64	84.0	68.0	0.81	69.0	61.7	0.89
1949	51.0	8.5	0.16	72.0	2.1	0.03	56.0	4.7	0.08	66.0	5.4	0.08	49.0	17.0	0.39
1950	52.8	7.9	0.15	71.9	0.15	0.002	51.0	2.2	0.04	65.0	11.6	0.18	60.0	33.4	0.67
1951	83.0	37.0	0.44	89.0	8.3	0.093	62.0	22.0	0.35	59.0	23.0	0.39	55.0	50.0	0.90
1952	50.0	19.1	0.38	62.0	3.2	0.051	45.0	20.4	0.45	104.0	28.4	0.27	39.0	31.2	0.80
1953	112.0	64.5	0.57	111.0	28.0	0.25	117.0	44.5	0.38	110.0	82.5	0.79	94.0	88.0	0.94
1954	28.0	1.8	0.06	50.0	0.0	0.0	45.0	2.2	0.05	30.0	4.5	0.15	14.0	2.6	0.19
1955	32.0	19.5	0.61	—	—	—	—	—	—	50.0	35.0	0.70	31.0	27.0	0.87
1956	54.0	24.0	0.45	—	—	—	—	—	—	—	—	—	45.0	34.8	0.77
1957	48.0	15.8	0.38	—	—	—	—	—	—	—	—	—	41.0	23.0	0.56
1958	55.0	27.8	0.20	—	—	—	—	—	—	—	—	—	58.0	40.5	0.68
Average	73.5	30.4	0.41	108.0	15.1	0.14	85.0	27.7	0.34	82.2	39.2	0.47	69.6	46.3	0.67

The smallest runoff and runoff coefficient were observed on the Selektsentrovskaya Ravine where the forest cover on the catchment constituted 18%, next in order were the Lesnaya Ravine (forest cover 6% and the Ozerki Ravine (forest cover 3.6%). The greatest runoff and runoff coefficients were observed on the steppe catchment of the Osinovaya Ravine (forest cover 0%). On the steppe catchment of the Krasnaya Ravine with similar natural conditions, observations on runoff of melt water were carried out over a period of 7 years from 1935 to 1941.

The data are given in Table 5.

TABLE 5

RUNOFF DATA FOR THE CATCHMENT OF THE KRASNAYA RAVINE

	1935	1936	1937	1938	1939	1940	1941	Average for 1935-41
Water equivalent of snow in Spring, mm	58.6	44.8	44.7	55.6	36.4	125.0	106.4	67.3
Runoff, mm	4.8	26.8	15.7	45.0	21.0	111.0	74.0	42.8
Runoff coefficient	0.081	0.60	0.35	0.81	0.58	0.89	0.70	0.64

Runoff data for this catchment are similar to those for the catchment of the Osinovaya Ravine for corresponding years.

Runoff data for the catchments of the Sukhaya Chigla, Berezovaya, Talovaya, Kamenka, Khorol'skaya, and Dubovaya Ravines are given in Table 6.

TABLE 6

RUNOFF FROM THE CATCHMENTS OF THE SUKHAYA CHIGLY, BEREZOVAYA, TALOVAYA, KAMENKA, KHOROL'SKAYA, AND DUBOVAYA RAVINES

Ravine	Catchment area, km^2	Spring runoff, mm									
		1950	1951	1952	1953	1954	1955	1956	1957	1958	Average runoff, mm
Sukhaya Chigla	140.0	—	65.1	25.3	61.4	1.8	19.1	24.0	15.8	25.0	29.7
Berezovaya	113.0	·	87.0	24.6	86.0	2.1	15.0	28.2	17.0	32.1	36.5
Talovaya	90.0	--	78.0	29.6	82.5	2.4	16.8	24.1	19.5	35.2	36.0
Kamenka (sect. vill. N. Kamenka)	35.0	31.7	74.7	41.4	105.5	5.3	23.3	30.8	24.0	43.6	42.2
Khorol'skaya	17.5	...	62.0	30.8	63.7	2.2	12.6	27.4	16.7	31.8	30.8
Kamenka (sect. vill. Dubov)	15.6	---	80.4	24.5	92.3	4.6	20.2	25.7	15.6	29.8	36.6
Dubovaya	7.0	--	66.0	55.1	74.6	9.5	8.1	17.5	12.5	25.8	33.6
Average			73.4	33.0	81.0	4.0	16.4	25.4	17.3	32.0	35.0

R e m a r k. On the catchment of the Talovaya Ravine observations of runoff were made also in subsequent years. In 1959 the runoff was 19.6 mm, in 1960 - 16.1, in 1961 - 11.8 and in 1962 - 12.8 mm. Average runoff from this catchment for 12 years (1951-1962) was 29.1 mm.

This table shows that the average runoff for 1950-1958 for all catchments ranged from 4.0 to 73.4 mm. The average for eight years was 35.0 mm. The greatest runoff was observed from the catchment of the Kamenka Ravine and the smallest from the catchment of the Sukhaya Chigla Ravine. On this catchment the runoff was 18-20% smaller than that from the similar steppe catchments of the Talovaya, Osinovaya, Kamenka, Berezovaya and of other ravines. The large reduction in runoff on the catchment of the Sukhaya Chigla Ravine can be explained by the considerable "completeness" of the basin and by the presence of a large number of ponds and reservoirs which every year store no less than 7-8 mm of melt water. The amount of melt water retained by large ponds and reservoirs on all the catchments was recorded every year. Observations of runoff on the catchment of

the Talovaya Ravine were made until 1962. The average runoff from this catchment for 1951-1962 was 29.1 mm.

The rate of runoff is affected by: weather conditions in the winter and in the snow melting period, by the nature of freezing of the soil, by its moisture and by other natural conditions which are the same on all the considered catchments. However, each of the above-described catchments has its peculiarities. They differ in shape, slope, prevailing exposure of slopes, drainage density and in other respects.

These physical-geographical characteristics are combined differently on each of the catchments.

The fluctuations in weather conditions of the fall, winter and Spring exert a strong influence on the changes in runoff over a long period of years. These fluctuations are the same on all the catchments of this region.

Of the steppe catchments the Osinovaya Ravine has the longest period of record. We therefore set up regression equations between runoff from the Osinovaya Ravine catchment and that from the catchments of the Talovaya, Kamenka, Khorol'skaya, Dubovaya, Berezovaya and the Sukhaya Chigla Ravines. The calculations show a considerably close correlation between the runoff of the examined catchments. The correlation coefficients of the regressions ranged from 0.96 to 0.98 (Table 7).

TABLE 7

REGRESSION EQUATIONS OF RUNOFF OF THE OSINOVAYA RAVINE ON THE RUNOFF FROM THE OTHER KAMENNAYA STEPPE CATCHMENTS

Ravine	Indices of correlation of runoff from the different catchments			
	Correlation coeff. $r_{x,y}$	Probable error of the correlation coefficient	Regression equation	Fisher's number
Talovaya	0.98	0.01	y $1.05x - 5.5$	5.18
Berezovaya	0.97	0.014	y $1.15x$ 8.9	4.68
Kamenka (sect. vill. N. Kamenka).	0.98	0.04	y $1.18x - 3.1$	5.18
Khorol'skaya	0.97	0.01	y $0.78x - 0.6$	4.68
Kamenka (sect. vill. Dubov)	0.98	0.01	y $1.15x - 9.2$	5.18
Dubovaya	0.87	0.06	y $0.84x - 0.2$	2.97
Stepnaya	0.86	0.07	y $0.87x - 1.1$	2.54
Sukhaya Chigla	0.96	0.02	y $0.98x$ 8.9	4.34

Table 7 includes also values of the probable errors of the correlation coefficients and the regression equations of the runoff from the catchment of the Osinovaya Ravine (x) on the runoff from the catchments of the other ravines (y).

The Fisher number is the criterion of the stability of the correlation between hydrologic arrays. With Fisher values greater than 2.5 it can be considered that the correlation of the hydrologic array is stable and the correlation coefficient is not fortuitous.

As is seen in Table 7 the Fisher number for all the catchments is greater than 2.5.

With the regression equations and the Osinovaya Ravine records the runoff from the catchments of the several ravines was converted to a long-term array and the missing records from 1942 to 1947 on the Stepnaya Ravines were filled in.

Derived values of runoff from the above-named catchments for 1935-1962 are given in Table 8.

Table 8 shows that in individual years the Spring runoff from the Kamennaya Steppe catchments fluctuates sharply. The maximum runoff observed in 1942 ranged from 138.5 on the catchment of the Kamenka Ravine down to 93.8 mm on the catchment of the Dubovaya Ravine. The average maximum runoff for the eight catchments was 110.6 mm. Minimum runoff on the catchments observed in 1954 ranged from 5.3 to 2.1 mm and averaged 4.2 mm. The average long-term mean runoff ranged from 47.8 to 33.4 mm; the average for the 8 catchments being 40.4 mm.

Thus in a wet year the runoff was 260% of normal, and in a dry year it dropped to 10.3% of normal.

Table 8 shows also that the last 9 years were drier than the preceding years.

These data indicate some tendency of a gradual reduction in local runoff under the influence of Man's agricultural activities.

Table 8 shows further that under conditions of the steppe zones of the CCB and especially in its southeastern part, local runoff is characterized by strong variability from year to year.

TABLE 8

RUNOFF FROM THE KAMENNAYA STEPPE CATCHMENTS, mm

	Berezovaya rav. at Orlovka	Talovaya rav.	Kamenka rav. at N. Kamenka	Osinovaya rav.	Khorol'skaya rav. at Khorol'sk	Kamenka rav. at Dubov	Dubovaya rav. at Bogatyr'	Stepnaya rav.	Av. runoff for all catchments
1935		2.1	5.4	7.2	5.0	3.5	5.8	11.6	6.2
1936	43.6	42.4	50.8	45.7	35.0	43.3	38.1	42.7	42.6
1937	21.3	22.1	27.9	26.3	19.9	21.0	21.8	24.0	24.3
1938	73.2	69.4	81.1	71.4	55.1	79.9	59.7	41.5	66.3
1939	20.4	21.3	26.0	25.5	19.3	20.1	21.2	24.2	22.3
1940	104.9	98.4	113.7	99.0	76.6	104.6	82.9	61.0	92.5
1941	119.9	112.1	129.1	112.0	86.8	119.6	93.8	102.0	100.9
1942	129.1	120.5	138.5	120.0	93.0	128.8	100.6	103.3	110.6
1943	32.0	31.8	38.9	35.6	27.2	31.7	29.7	29.8	32.4
1944	2.3	4.8	8.5	9.8	7.0	2.1	8.0	7.4	6.2
1945	31.3	31.2	38.2	35.0	26.7	31.1	29.2	29.3	31.3
1946	56.3	54.0	63.8	56.7	43.6	56.0	47.4	48.2	53.3
1947	56.4	54.1	63.9	56.8	43.7	56.1	47.5	48.3	53.2
1948	62.1	59.2	69.7	61.7	47.5	61.7	51.6	23.0	54.4
1949	10.6	12.3	17.0	17.0	12.6	10.3	14.1	28.4	15.3
1950	29.5	29.6	31.7	33.4	25.4	29.2	27.8	11.6	27.3
1951	87.0	78.0	74.7	80.0	62.0	80.4	66.0	23.0	69.1
1952	24.6	29.6	41.4	31.2	30.8	24.5	55.1	28.4	33.2
1953	86.0	83.0	105.5	88.0	63.7	92.3	74.6	82.5	84.6
1954	2.1	2.4	5.3	2.6	2.2	4.6	9.5	4.5	4.2
1955	15.0	16.8	23.3	27.0	12.5	20.2	18.1	35.0	21.0
1956	28.2	24.1	30.8	34.8	27.4	25.7	17.5	37.0	27.2
1957	17.0	19.5	24.0	23.0	16.7	15.6	12.5	25.0	19.1
1958	32.1	35.5	43.6	40.5	31.8	29.8	25.8	36.4	34.5
1959	19.6	19.4	26.1	24.7	18.6	19.3	20.6	20.4	21.4
1960	16.1	16.1	22.5	21.7	16.3	15.7	18.5	17.8	18.1
1961	11.6	11.8	18.1	17.9	13.4	11.3	14.9	14.5	14.2
1962	11.2	12.8	17.6	17.4	13.1	11.0	14.4	14.3	14.0
Average	41.3	40.0	47.8	43.9	33.4	41.1	36.5	35.5	40.4

According to the data of K.P.Voskresenskiy (1956) the coefficient of variation of Spring runoff for Kamennaya Steppe conditions is equal to 0.50 while, according to our calculations it ranges from 0.60 to 0.70. Therefore, the magnitude of the error of the arithmetic mean (the error of the mean) of the hydrologic array consisting of 28 years ranges from 10 to 14% and the probable error (E=50%) from 7 to 10%. According to K.P.Voskresenskiy's (1956) data the coefficient of variation of Spring runoff is least along the northern boundary of the forest steppe zone. Therefore the coefficient of variation of the hydrologic array reduces, i.e., its variability from year to year decreases from south to north.

Runoff from Small Catchments in the Kursk Province

The local runoff for the Kursk Province can be represented by the data from several small catchments of the river and ravine net (Kur River, Rat' Creek and the Tsvetovo, Erokhina Paseka, Polonovskiy Log, and Blizhnyaya Dubrava Ravines) collected by the Gidroprovodkhoz and the Administration of the Hydrometeorological Service of the Central Chernozem Provinces (CCP).

The Catchment of the Kur River lies north of the Town of Kursk. The catchment area at the measuring section at the Kazatskaya Sloboda is equal to 66 km^2; the length of the catchment is 2.6 km. The soils are of the gray forest type. The area of the catchment is quite highly dissected by a gully-ravine net. It should be noted that the dry weather discharges of the Kur River

do not exceed 30-70 lit/sec and that in individual years the river dries out completely during the summer period.

The Catchment of the Rat' Creek lies in the northeastern part of the Kursk Province, 50 km to the northeast of Kursk. The area of the catchment of the creek is 62 km^2, the closing gaging section of this part of the catchment is located at the Village Ozerki. The soils are of the gray forest type. Within the boundaries of the investigated catchment Rat' Creek, like the Kur River, is an intermittent watercourse because during the summer period the water discharge of this creek does not exceed 30-70 m/sec. and in dry years it very often dries up completely.

The Catchment of the Tsvetovo Ravine is located on the land of the Villages Tsvetovo I and Tsvetovo III of the Streletskiy District. The catchment lies 3-4 km south of Kursk. The Tsvetovo Ravine is an intermittent watercourse since only floods of Spring melt water pass through it. In the summer it dries out completely. The area of the catchment is 20.5 km^2, its length is 7.5 km, the width of the basins is 3.5 km and the slope of its surface is 0.037. The soils are ordinary chernozem. The catchment of the ravine is almost entirely cultivated.

The Catchment of the Erokhina Paseka Ravine is located on the land of the Village Kotel'niki of the Oboyanskiy District. The area of the catchment is 1.1 km^2, the part of the catchment under

consideration drains into a pond constructed in the summer of 1955 which regulates the 1% frequency flow of melt waters. The soil of the catchment is ordinary chernozem; the entire catchment of the ravine is cultivated.

The Catchment of the Polonovskiy Log Ravine is located also on the land of Village Kotel'niki in the Oboyanskiy District adjacent to the catchment of the Erokhina Paseka. The catchment area is 3.37 km^2, the part of the catchment under consideration drains into a pond constructed in 1955 which completely regulates the local runoff (with a frequency of 1%). The soil of the catchment is ordinary chernozem, the catchment of the ravine is completely cultivated.

The catchment of the Blizhnyaya Dubrava Ravine is located on the land of the "Plodopitomnik" State Farm of the Oboyanskiy District. The area of the catchment is 0.5 km^2, the entire catchment is occupied by a fruit orchard of the state farm. The catchment drains into a pond constructed in the gully in 1956 designed to regulate the 1% frequenty flow. The soil of the catchment is an ordinary chernozem.

Runoff Data

On the catchments of the intermittent watercourses, the Kur River and the Rat' Creek, observations of runoff of melt water began by the Administration of the Hydromet Service of the CCP in 1946 and 1947 respectively.

We utilized the 1946-1949 data for the Kur River and the 1947-1959 data for Rat' Creek.

Because the catchment of the Tsvetovo Ravine lies at a distance of 5-7 km from the catchment of the Kur River the fall and winter conditions,i.e., the nature and conditions of snow melting on these two catchments are the same. These catchments differ only in their soils.

On the catchment of the Tsvetovo Ravine runoff observations were made by Giprovodkhoz in 1950, 1951, 1952, and 1953. Runoff from the catchment for the indicated four years was respectively 12.4, 98, 36, and 63 mm. The runoff was measured on the catchment of the pond located in the Village Tsvetovo I. We resumed observations of Spring runoff on this catchment in the Spring of 1959. The runoff from this catchment in 1959 was 32.4 mm. A sufficiently close relationship was found between the runoff from the Tsvetovo Ravine and from the Kur River. The regression equation of the runoff from these catchments is of the following form:

$$y = x - 24.3,$$

where y - the runoff from the Tsvetovo Ravine catchment. x - runoff from the catchment of the Kur River in mm.

The runoff from small catchments of three ravines: Erokhina Paseka, Polonovskiy Log and Blizhnyaya Dubrava located in the Oboyanskiy District was computed from the Spring filling of the ponds. In surveying these ponds in 1958 and in 1959 we obtained data on their Spring filling

for the years 1955, 1956, 1957, 1958 and 1959. Observations on the filling of the ponds on the Erokhina Paseka and Polonovskiy Log Ravines were made by A.N.Konev, a member of the Lenin kolkhoz (Village Kotel'niki), those on the Blizhnyaya Dubrava Pond in the state farm "Plodopitomnik" were made by A.N.Chebotarev, Hydraulic Engineer of the Oboyanskaya Reclamation Station. The runoff data for the three indicated catchments are given in Table 9.

TABLE 9

RUNOFF FROM SMALL CATCHMENTS IN THE OBOYANSKIY DISTRICT OF THE KURSK PROVINCE FOR 1955 - 1959

Ravine	Catchment area, km^2	1955	1956	1957	1958	1959
Erokhina Paseka	1.1	40.7	21.4	9.1	34.0	25.4
Polonovskiy Log	2.37	42.3	19.1	6.7	31.0	28.0
Blizhnyaya Dubrava	0.50	-	-	2.1	10.1	6.1

The table shows that the runoff values from the catchments of the Erokhina Paseka and the Polonovskiy Log Ravines are similar for all years of observation. These two small catchments are completely plowed. The runoff from them is therefore small. However, the runoff from the Blizhnyaya Dubrava catchment for these years was 3-4 times smaller. The smaller runoff on this catchment is due to the fact that the entire catchment of this ravine lies within the fruit orchard of the "Plodopitomnik" State Farm. The orchard is plowed late in the fall.

In the winter this catchment has a deep uniformly distributed snow cover so that the soil freezes to a smaller depth and the possibility of forming of an ice crust on the surface of the soil is lessened. It is for this reason that runoff from this catchment is smaller than from the catchments with plowed fields. A close relationship is observed between the runoff from the catchments of the Oboyanskiy District and that from the catchment of the Kur River.

We set up regression equations between the flows of the Erokhina Paseka and Polonovskiy Log Ravines and that of the Kur River. These regressions are of the following form:

For the catchments of the Erokhina Paseka Ravine and the Kur River:

$$y = 0.64\,x - 5$$

For the catchments of the Polonovskiy Log Ravine and of the Kur River:

$$y = 0.72\,x - 9.8$$

where y - the runoff from the catchments of the Erokhina Paseka and the Polonovskiy Log Ravines, and x - the runoff from the catchment of the Kur River in mm.

Table 10 contains information on the water equivalent of snow, Spring runoff, and the runoff coefficients for the catchments of the Kur River and Rat' Creek as well as the runoff from the catchments of the Tsvetovo, Erokhina Paseka and the Polonovskiy Log Ravines converted to a long-term period of record (1946-1958).

TABLE 10

WATER EQUIVALENT OF SNOW (P, mm), SPRING RUNOFF (C, mm) AND RUNOFF COEFFICIENTS FOR THE CATCHMENTS OF KUR RIV.; RAT' CR.; AND TSVETOVO, EROKHINA PASEKA, AND POLONOVSKIY LOG RAVINES

	Kur			Rat'			Tsvetovo			Erokhina Paseka			Polonovskiy Log		
	P	C	K	P	C	K	P	C	K	P	C	K	P	C	K
1946	108.0	94.5	0.87	—	—	—	104.0	70.2	0.68	97.0	57.0	0.59	97.0	57.2	0.59
1947	154.0	140.0	0.91	134.0	126.0	0.94	132.0	115.7	0.88	126.0	85.3	0.68	126.0	90.2	0.71
1948	80.0	29.8	0.38	115.0	51.5	0.45	78.0	9.7	0.12	72.0	12.8	0.18	72.0	11.5	0.16
1949	85.0	77.7	0.90	80.0	45.7	0.57	85.0	53.4	0.63	78.0	45.0	0.58	78.0	45.6	0.58
1950	70.0	34.1	0.49	70.0	31.3	0.45	71.0	11.7	0.18	64.0	17.0	0.28	64.0	14.7	0.23
1951	138.0	125.0	0.91	140.0	133.5	0.96	134.0	98.0	0.73	127.0	77.0	0.60	127.0	80.2	0.64
1952	74.0	68.3	0.92	138.0	125.0	0.91	74.0	36.0	0.49	69.0	38.5	0.56	69.0	39.2	0.57
1953	97.0	85.0	0.88	124.0	114.0	0.93	97.0	63.0	0.65	90.0	49.5	0.65	90.0	51.5	0.57
1954	85.0	29.8	0.35	55.0	16.9	0.31	85.0	8.7	0.10	78.0	14.0	0.18	78.0	11.7	0.15
1955	78.0	72.8	0.93	94.0	85.0	0.91	78.0	48.5	0.63	71.0	41.0	0.58	71.0	38.0	0.54
1956	96.0	44.9	0.47	110.0	49.5	0.45	96.0	20.1	0.21	89.0	21.4	0.24	89.0	19.1	0.21
1957	59.0	22.7	0.38	75.0	65.3	0.85	59.0	7.3	0.12	52.0	9.1	0.17	52.0	6.7	0.13
1958	58.0	51.0	0.89	70.0	58.6	0.84	58.0	26.0	0.45	51.0	34.0	0.68	51.0	31.0	0.61
1959	76.0	53.3	0.73	79	62.8	0.79	76	32.4	0.42	69.0	25.9	0.38	69.0	28.0	0.41
Average	90.7	66.5	0.73	98.8	74.3	0.75	87.7	42.8	0.49	81.0	37.6	0.47	81.0	37.8	0.47

This table shows that on the catchment of the Kur River, Spring runoff ranges from 22.7 to 140 mm and averages 66.5 mm. The runoff coefficient ranges from 0.35 to 0.93 and averages 0.73. The retention of snowmelt on the catchment ranges from 5.2 to 55.2 mm and for the long-term period averages 24.3 mm.

On the catchment of the Rat' Creek the Spring runoff over the years ranges from 31.3 to 133.5 mm and averages 74.3 mm, the runoff coefficient ranges from 0.31 to 0.96 and averages 0.75, and the retention of snowmelt on this catchment ranges from 9 to 63.5 mm and averages 24.5 mm. It should be noted that the runoff and retention of snowmelt on the two catchments are close. Table 10 shows a sufficiently high mean long-range runoff and runoff coefficients for the two indicated catchments. On the average, 73-75% of snowmelt runs off these catchments and only 25-27% is retained (on fields, in ponds, and otherwise). The large runoff and the relatively small retention of snowmelt can be explained by the high moisture in the upper horizons of the soil during the fall and winter periods, by the forming of an ice crust on the field during winter thaws and also by the water properties of the gray forest soils. As indicated above, the permeability of gray forest soils is low. Fall rains cause slaking of the upper layers of the soil so that the permeability during the period of Spring snowmelting is reduced. The extent of slaking of forest soils during the fall varies greatly depending on weather conditions in the fall.

The permeability of the soil therefore changes markedly from year to year.

Observations show that the rate of infiltration on chernozem soils during the summer ranges from 0.9 to 1.5 mm/min. while on the gray forest soils it ranges from 0.4 to 0.8 mm/min. Therefore, the permeability of gray forest soils is, on the average, half that of ordinary chernozem.

As was already noted above, the soils of the catchments of the Tsvetovo, Erokhina Paseka and Blizhnyaya Dubrava Ravines are ordinary chernozem.

On the catchment of the Tsvetovo Ravine the runoff ranges from 7.3 to 115.7 mm, the 14-year average is 42.8 mm. The average runoff coefficient for the 14 years was 0.52 ranging from 0.10 to 0.88. It is interesting to note that the runoff as well as the coefficient of runoff on the catchment of the Tsvetovo Ravine are considerably lower than on the catchment of the Kur River. The retention of snowmelt on the catchment of the Tsvetovo Ravine ranges over the years from 16 to 74 mm and averages 44.8 mm. On the catchment of the Kur River, the average retention of snowmelt is 24.3 mm. Therefore, the average retention of snowmelt on the catchment of the Tsvetovo Ravine with chernozem soils and completely plowed is 20.6 mm i.e., 1.8 times greater than on the catchment of the Kur River with gray forest soils.

The 14-year average runoff from the catchment of the Erokhina Paseka Ravine was 37.6 mm. On the catchment of the Polonovskiy Log Ravine it was 37.8 mm. The average long-term runoff coefficient is 0.47. Over a long-term period 43.4 mm of melt water was retained on the catchment of the Erokhina Paseka Ravine and 43.2 mm on the catchment of the Polonovskiy Log Ravine.

As already noted above, under the conditions of the CCB local runoff is more variable than the flow of the river net. For the conditions of the Town of Kursk the coefficient of variation of flow of intermittent water-courses is, according to K.P.Voskresenskiy (1956), equal 0.50, while for those of the Town of Oboyan' it is 0.60. The coefficients of variation for the catchments of the Kur River, the Rat' Creek and the Tsvetovo, Erokhina Paseka and Polonovskiy Log Ravines are shown in Table 11.

TABLE 11

VALUES OF THE COEFFICIENTS OF VARIATION OF RUNOFF FROM CATCHMENTS IN THE KURSK PROVINCE

	Years of record	Coeff. of variation	Error of mean (normal) runoff (±),%	Probable error (±) %
Kur riv.	14	0.53	14.0	9.4
Rat' cr.	13	0.52	15.0	10.0
Tsvertovo rav.	14	0.66	17.0	11.0
Erokhina Paseka rav. . . .	14	0.70	18.0	12.1
Polonovskiy Log rav. . . .	14	0.70	18.0	12.1

The presented table shows that the coefficients of variation of runoff for the catchments of the Kur River on Rat' Creek are close to the values given by K.P.Voskresenskiy (1956). For the catchment of the Tsvetovo Ravine Cv=0.66 and for the catchments of the Erokhina Paseka and Polonovskiy Log Ravines (Oboyanskiy District) Cv=0.70. Thus, the coefficient of variation increases towards the south. The high value of Cv for runoff from catchments of the ravine net indicate a strong variability in the hydrologic array of these catchments from year to year.

Effect of Ice Crust on Runoff

The wetting of the ordinary chernozem soils in September and October, i.e., long before the freezing of the soil exerts no great influence on the increase in runoff of snowmelt during the following Spring. However, rains falling late in the fall before the onset of freezing of the soil (fall ice storms, winter thaws) greatly saturate the upper layers of the soil, reduce its permeability and are conducive to an increase in Spring runoff.

In 1954/55 and 1955/56 we conducted observations at Kamennaya Steppe on runoff of snowmelt on 400 m^2 (40 x 10) plots with different fall wetting accomplished by a sprinkler installation (KGU-41).

In 1954/55 the runoff plots were located on a slope with an eastern exposure and were plowed late in the fall.

On 10 October, 1954 three plots were sprinkled with 50, 100 and 150 mm of rain. The fourth plot (the control) was under natural moisture conditions. The slopes of the runoff plots ranged from 0.014 to 0.017. The runoff coefficients of snowmelt on the sprinkled plots was respectively 0.55, 0.49 and 0.55. On the controlled plot the runoff coefficient was 0.45.

The 1955/56 experiments were made on a field in winter wheat. The runoff plots were located on areas in this crop on which 25, 50, 100 and 150 mm of water was applied during the period from 4 to 10 September, 1955. The coefficient of runoff of these runoff plots was respectively 0.69, 0.51, 0.64 and 0.73. On the control plot it was 0.56. The data of these experiments showed that September and October wetting of the soil does not greatly increase runoff. Therefore, the water reaching the soil in early fall prior to freezing is uniformly distributed in the soil and penetrates into deeper layers without supersaturating its upper horizons. However, rains occurring prior to the onset of freezing of the soil, fall sleet storms, and thaws with snowfall supersaturate the upper layers of the soil and the water freezes in the upper layer. With freezing all the empty pores of the soil are filled with ice, and the soil becomes almost impermeable. The ice crust formed on the soil surface after winter thaws exerts a great influence on runoff.

To clarify the role of the ice crust in increasing runoff of snowmelt we shall present data for a number of years for the catchment of the Osinovaya Ravine - years when an ice crust was formed on the soil surface and years when there was no ice crust (Table 12).

These years are similar with respect to: precipitation occurring in November and December of the preceding years, mean monthly temperatures for January, February and March and also with respect to water equivalent of snow prior to snow melting. Table 12 shows that runoff and the runoff coefficient differ greatly for the compared years. On the average for three years without ice crusts the runoff was 11.3 mm and the runoff coefficient was 0.22. In the presence of an ice crust the runoff for the three years averaged 65.0 mm and the runoff coefficient averaged 0.94. Thus, the average runoff for the years with ice crust was 5.7 times and the runoff coefficient 4.3 times greater than in years when there was no ice crust on the surface of the soil prior to the snow melting in the Spring.

The nature of the ice crust, its thickness, and its extent vary from year to year; in some years it occurs everywhere and is of considerable thickness (1952, 1953, 1955). In other years it is more strongly expressed on slopes with southern and southeastern exposures. The effect of the ice crust on runoff is therefore manifested differently in different years.

TABLE 12

EFFECT OF ICE CRUST ON RUNOFF FROM THE CATCHMENT OF THE OSINOVAYA RAVINE

	Total precipitation, mm		Average air temperature (Jan.-Mar.) °C.	Water equivalent of snow prior to melting, mm	Spring runoff, mm	Runoff coefficient
	Nov.-Dec.	Jan.-March				
In years without ice crust						
1934/35	31.0	28	-7.1	61.6	7.2	0.11
1938/39	58.7	24	-6.9	49.0	17.0	0.39
1943/44	48.0	58	-3.1	45.9	9.8	0.21
Average	46.4	36.6	-5.6	51.8	11.3	0.22
In years with ice crust						
1937/38	58.0	61	-5.3	74.7	71.4	0.95
1951/52	38.6	58.8	-7.2	39.0	31.2	0.80
1952/53	36.2	89.0	-9.5	94.0	88.0	0.94
Average	44.3	69.0	-7.3	69.0	65.0	0.94

A similar effect of the ice crust on runoff and on the runoff coefficient was revealed also by the observations on runoff plots (Table 13). In this table runoff from late fallow and from steppe virgin land for 1950/51 are compared with the runoff for 1955/56.

TABLE 13

EFFECT OF ICE CRUST ON RUNOFF FROM RUNOFF PLOTS

	Fall plowed			Steppe (virgin land)		
	Water equivalent of snow, mm	Runoff, mm	Runoff coefficient	Water equivalent of snow, mm	Runoff, mm	Runoff coefficient
1950/51	61.5	3.4	0.05	109.0	31.0	0.27
1955/56	25.0	1.3	0.05	181.0	120.0	0.66

In the winter of 1950/51 there was no ice crust on the surface of the soil, in 1955/56 an ice crust was formed during the winter thaw at the end of the second 10-days of December only on land in winter crops, in grass and on the steppe (virgin land) and others. Because of the higher permeability of the soil there was no ice crust on fall plowed land.

Table 13 shows that while in the Spring of 1951 the runoff coefficient on the steppe was 5.4 times higher than that on fall-plowed land, in 1956 when there was an ice crust on the virgin land the runoff coefficient on it was 13 times higher than that on fall-plowed land.

Thus, on the basis of the presented experimental data it can be considered that under conditions of the steppe zone of the CCP, the ice crust on the soil surface increases runoff 5-10 times and the runoff coefficient 4-9 times as compared with the runoff in years when there is no ice crust on the soil surface.

The analysis of data on soil moisture prior to snow melting showed that in years when an ice crust is formed, soil moisture is sometimes lower than in years when there is no ice crust. In the first case there is observed only a supersaturation of the upper horizon of the soil 0-20 cm from the surface, below that the moisture content of the soil remained low.

After the December thaw in 1955 we took soil samples on a field in alfalfa (the irrigated crop rotation of the steppe), where a continuous ice crust 5-7 cm thick was formed, to determine the soil moisture in the meter layer; the samples were taken where the crust was the thickest. In the upper layer of the soil down to 10 cm, soil samples were taken at 2 cm intervals.

The results were as follows:

Depth of soil sampling, cm.	0-2	2-4	4-6	6-8	8-10	10-20	20-40	40-60	60-80	80-100
Moisture by weight, %	212	51.9	35.2	33.4	33.7	27.6	21.7	18.8	19.2	18.2

These observations show that the formation of the ice crust is due to the supersaturation of only the uppermost pulverized layer of the soil. At a depth of 20 cm and lower,

the soil moisture does not exceed 20% by weight. The presented data show that strong supersaturation of the soils with the attendant filling of the pores is observed in the upper 4 cm of the soil. The upper layer 0.2 cm had a large number of ice crystals. For this reason the moisture content of this layer was 212 (by weight of dry soil).

Observations show that under the conditions of the steppe zone and of the forest-steppe of the CCP thaws and the formation of an ice crust occur in about half the winters. During the last 10 years such winters at Kamennaya Steppe were 1947/48, 1951/52, 1952/53, 1954/55, 1955/56, 1957/58.

It should be noted that with respect to their harmful consequences in the southeast of the CCP the winter thaws can be divided into two groups: 1) protracted thaws lasting 12-18 days with considerable or complete thawing of the soil and subsequent mild freezes with snow cover; 2) brief thaws (3-4 days) with rainfall and subsequent periods of severe freezes without thawing of the soil.

In the first case a considerable part of the melt water has time to penetrate into the soil or to run off the fields. With the onset of subsequent mild freezes a thin (1-2 cm) ice crust is formed only locally. On fall-plowed land there is often no ice crust after such thaws. After these thaws melt water accumulates only in depressions. Melt water on these elements of the relief remain there during a protracted period; it freezes with the onset of frost

and the soil surface in these depressions becomes covered by a thick layer of ice (10-30 cm thick). In such years winter crops completely perish in places of water accumulation. Such thaws were observed in the winters of 1951/52, 1952/53, and 1956/57.

In the second case, i.e., with short thaws, (3-4 days) with a subsequent period of strong frost an ice crust is, as a rule, formed almost everywhere, on winter crops, grass, virgin land, pasture, and on fall-plowed land.

Very often during such thaws rains occur. The rain water and snowmelt which accumulate on the surface of the soil do not have time to run off the slope and freeze with the onset of low temperatures. In such years an ice crust of considerable thickness is formed everywhere. The described type of thaws occurred in the winters of 1947/48, 1954/55, 1955/56.

The measures used to eliminate the crust and to reduce the possibilities of its formation include: snow retention on fields, keeping the upper layer of the soil in a friable state, blackening the spots where the crust is formed (sprinkling ashes or soil), leveling of the fields, and others.

Effect of Winter Precipitation on Runoff

Investigations conducted at Kamennaya Steppe showed that the effect of the snow cover on runoff is great and is manifested differently depending on weather conditions in the winter and during the snow melting period.

We made an analysis of the obtained data on water equivalent of snow prior to snow melting on the catchment of the Osinovaya Ravine for the period from 1935 to 1957 and compared these data with snowmelt runoff.

The results of this comparison showed that with an increase in the water equivalent of snow the runoff coefficient and in some years also of the runoff from the catchment, tend to diminish. It was also found that the relationship of runoff to the water equivalent of snow is manifested differently. Spring runoff from the catchment of the Osinovaya Ravine as a function of winter precipitation is shown in Figure 1. It is seen in the graph that through the plotted points three regression lines can be drawn which reflect the peculiarities of the winter and of the snow melting period.

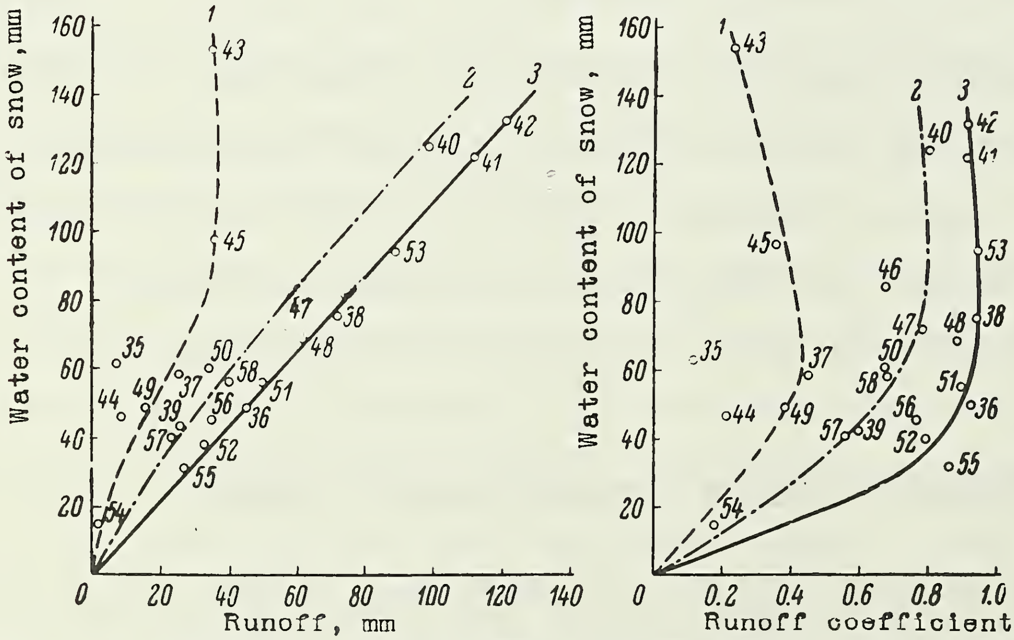

FIG. 1. Relation of Runoff and of the Runoff Coefficient to the Water Content of the Snow Cover.

1 - Years with warm winters; 2 - With cold winters and ice crust the surface of the catchment; 3 - With cold winters and a thick ice crust everywhere. Figures at points correspond to the two last digits of the years of observation as shown in Table 14.

Curve No. 1 represents warm and average winters with a deep and average, quite uniform snow cover and shallow freezing of the soil (40-50 cm). The snow cover during the entire winter is stable. There are no winter thaws. The winters are moderate with respect to the temperature regime. Beginning in the fall the moisture content of the soil was low (dry fall) and the snow melting in the Spring was slow or average. Curve No. 2 represents average and cold winters with small winter thaws and with ice crusts forming locally or generally; winters with stable but shallow snow cover; deep freezing of the soil and average or rapid snow melting in the Spring. Curve No. 3 represents average and cold winters with considerable wetting of the soil in the fall, with thin non-uniform snow cover, and with winter thaws and subsequent sharp cooling which are conducive to the formation of a thick ice crust. Spring thawing in these years is rapid or average. An ice crust on the soil surface leads to considerable supersaturation of the upper layers of the soil and to a reduction in their permeability. A description of weather conditions of the winters and of the snow melting periods for all years (1935-1958) keeping in mind the peculiarities of the three designated groups of years is given in Table 14.

This table shows that the three groups of years (Curves 1, 2, and 3) have different winter temperature regimes and different conditions of forming of the snow cover and of its melting. Different combinations of these

TABLE 14

WINTER METEOROLOGICAL CONDITIONS OF INDIVIDUAL YEARS OF THE 1935-1958 PERIOD

	Water equivalent of snow prior to snow melting, mm	Runoff from the catchment, mm	Runoff coeff.	Mean air temperature (Jan.-Mar.) °C.	Duration of Spring snow melting, days	Average rate of snow melting, mm/day	Presence of ice crust prior to snow melting
1st Group							
1935	61.3	6.6	0.09	7.1	15	4.1	None
1937	59.1	22.2	0.38	-7.4	15	4.0	»
1943	152.5	31.0	0.20	-9.9	14	10.8	»
1944	45.9	8.4	0.18	-3.1	15	3.0	»
1945	97.0	30.3	0.31	-10.3	8	12.0	»
1949	42.8	12.8	0.30	-6.9	14	3.0	»
2nd Group							
1939	42.8	21.6	0.50	—7.4	15	2.8	None
1940	123.0	95.2	0.77	10.8	10	12.3	»
1946	83.7	52.0	0.62	-5.4	20	4.2	Present
1947	72.5	50.7	0.70	—8.1	19	3.8	»
1950	49.0	24.7	0.50	—10.0	8	6.2	None
1954	12.0	4.1	0.34	—13.7	8	1.5	»
1957	50.0	19.0	0.38	—5.7	13	3.8	Not everywhere
1958	44.0	21.0	0.48	-6.2	12	3.7	»
3rd Group							
1936	49.0	40.0	0.82	-7.3	23	2.1	Present
1938	74.7	64.2	0.86	—5.3	10	7.4	Present (1—5 см).
1941	121.0	114.5	0.95	-7.9	16	7.5	»
1942	131.8	124.9	0.95	-13.9	15	8.7	None
1948	69.0	57.9	0.84	—5.9	23	3.0	Present (1—5 см).
1951	89.0	68.8	0.78	11.8	9	9.9	None
1952	39.0	33.2	0.85	-7.2	14	2.8	Present
1953	94.0	84.4	0.90	-9.5	14	11.7	»
1955	43.0	19.7	0.46	—3.4	13	3.8	»
1956	62.0	28.2	0.45	—11.6	16	3.9	»

conditions determine the position of the points in Figure 1. Of the 24 years, 6 belong to the first group, 8 to the second, and 10 to the third, constituting correspondingly 25, 33 and 42%. In the steppe zone of the CCP winters of the first group (the most favorable winters) recur, on the average, once in four years; winters of the second group once in three years, and those of the third group occur every other year.

It is seen in Figure 1 that the winters most favorable for moisture accumulation (retention of melt water on the fields) are the winters of the first group. Then come those of the second. The greatest amount of melt water runs off in the Springs of the years of the third group. Figure 1 shows also that in the first group of years runoff increases with an increase in the water equivalent of the snow up to 70-80 mm. With a further increase of the water equivalent the rate of increase in runoff is reduced. In years of the second and third group the rate of increase of runoff with an increase of the water equivalent remains almost the same over the entire length of the curve.

Runoff coefficients for all years of record also vary differently for different groups of years. In the first group the runoff coefficient increases with an increase in the water equivalent of the snow up to 40-50 mm. Then the rate of increase in the runoff coefficient is reduced and with a water content of snow greater than 60 mm the runoff coefficient begins to decrease.

In the second and third groups of years the runoff coefficient also increases with an increase in the water content of the snow, but, this increase takes place up to definite limits, i.e., up to 40-60 mm. With a further increase in the water content above 60 mm the values of the runoff coefficient are stabilized. Thus, the water content of the snow affects the runoff coefficient differently in different years.

The reduction in runoff and the increase in retention of snowmelt on the fields can be accomplished by creating a uniform and stable snow cover on the catchment which protects the soil from excessive freezing and reduces the possibility of the formation of an ice crust. Such conditions can be created by afforestation of the cultivated land on the catchment. As was shown above, afforestation is conducive to a considerable reduction in the runoff of snowmelt. By afforestation of catchments, the conditions of forming of the spring snow melting and of runoff can be changed and the unfavorable conditions of runoff in the third group can be altered and made more like the conditions of snow melting and of runoff of the first and second groups of years. In support of the abovesaid, we shall present data on water equivalent of snow prior to melting and on the values of runoff and of runoff coefficients for the unfavorable years of the third group (10 years) on the steppe catchment of the Osinovaya Ravine and also on the catchments of the Lesnaya and Selektsentrovskaya Ravines with forest covers of 6 and 18% (Table 15).

TABLE 15

WATER EQUIVALENT OF SNOW AND RUNOFF FOR THE 3rd GROUP OF YEARS

	Catchment of the Osinovaya rav.			Catchment of the Lesnaya rav. 6% forested			Catchment of Selektsentrovskaya rav. 18% forested		
	Water equiv. of snow, mm	Runoff, mm	Runoff coeff.	Water equiv. of snow, mm	Runoff, mm	Runoff coeff.	Water equiv. of snow, mm	Runoff, mm	Runoff coeff.
1936	49.0	40.0	0.82	77.2	34.7	0.47	—	–	—
1938	74.7	64.2	0.86	90.8	28.4	0.31	124.6	0.50	0.003
1941	121.0	114.5	0.95	126.0	87.0	0.69	140.0	28.1	0.20
1942	131.8	124.9	0.95	—	—	—	173.0	45.6	0.26
1948	69.0	57.9	0.84	84.8	53.4	0.64	118.0	40.5	0.34
1951	89.0	68.8	0.78	62.0	22.2	0.35	89.0	8.3	0.09
1952	39.0	33.2	0.85	45.0	20.4	0.45	62.0	3.2	0.05
1953	94.0	84.4	0.90	117.0	44.4	0.38	—	—	—
1955	43.0	19.7	0.46	—	—	—	—	—	—
Average . . .	77.2	63.4	0.82	86.3	41.4	0.48	118.0	20.9	0.178

Table 15 shows the enormous role played by the forest cover of catchments in changing the conditions of forming of snowmelt runoff and in the reduction of the runoff coefficient. For all the years of observation the water equivalent of the snow on the catchment of the Osinovaya Ravine is considerably lower but the runoff and runoff coefficients are considerably higher than on the catchments of the Lesnaya and Selektsentrovskaya Ravines. With an increase in the forest cover of the catchments, runoff and the runoff coefficients are reduced. According to observations for five years (1938, 1941, 1948, 1951, 1952) the average water equivalents were 78.8, 86 and 106 mm respectively on the catchment of the Osinovaya, Lesnaya and Selektsentrovskaya Ravines. The runoff was 68, 43 and 16.1 mm and the runoff coefficient was correspondingly 0.86, 0.48, and 0.15. The presented data show that forest cover on catchments changes the conditions of forming of melt waters in unfavorable years (third group of years)

to those existing in favorable years, i.e., the years of the first and second group.

Effect of Agricultural Activity of Man on Local Runoff

Man's agricultural activity exerts a great influence on the formation of runoff of snowmelt and of intense rainfall water.

Reduction of runoff under the influence of agricultural activity is brought about by the implementation of a number of measures. For instance: afforestation of catchments, agrotechnical measures, and construction of ponds and reservoirs.

Let us discuss briefly the effects of the enumerated practices on runoff.

A f f o r e s t a t i o n o f c a t c h m e n t s is conducive to an increase in the water content of the snow on the average by 20-30%; in individual years (windy winters) there can be from 50 to 260% more snow on forested catchments than on open ones (steppe). Afforestation can reduce runoff by 30-50% and the coefficient of runoff by 40-60% as compared with unforested catchments. The amount of retained melt water on forested catchments can be 2-3 times greater than that on unforested ones.

Mean long-term data for 1938-1954 on water content of snow, values of the runoff coefficient and on values of retained melt water on four catchments of ravines in the Voronezh Province: Osinovaya (steppe catchment) Ozerki, Lesnaya and Selektsentrovskaya are given in Table 16.

The last three catchments have mature forest belts covering 3.6, 6.0 and 18.0% of their areas respectively.

TABLE 16

EFFECT OF AFFORESTATION ON RUNOFF OF MELT WATER FROM CATCHMENTS IN THE VORONEZH PROVINCE

Ravine	Forest cover, %	Average values for 17 years (1938-1954)							
		Water equiv. of snow in Spring		Melt water runoff		Runoff coeff.		Retention on the catchment	
		MM	%	MM	%			MM	%
Osinovaya	0.0	77.3	100.0	52.0	100.0	0.69	100.0	24.0	100.0
Ozerki.	3.6	83.5	108.0	30.4	58.0	0.42	61.0	48.5	202.0
Lesnaya	6.0	88.0	114.0	23.5	45.0	0.33	48.0	56.1	244.0
Selektsentrovskaya . . .	18.0	108.5	140.0	14.2	27.4	0.14	20.4	93.0	387.0

The values in Table 16 show quite well the important role of afforestation of catchments in the reformation (regulation) of local water runoff. Runoff on the catchments with a forest cover of 3.6, 6 and 18% is reduced by 42, 55 and 72.6% respectively as compared with steppe catchments.

The extent of reduction of runoff as a function of the forest cover of catchments is shown in Fig. 2. The greatest rate of decrease in runoff takes place with a forest cover of the catchment up to 6%. With a further increase in the percent of forest cover on the catchment the reduction in runoff takes place at a lower rate. Complete retention of the mean long-term runoff occurs with a very high percent of forest cover of the catchment (47%).

A g r o t e c h n i c a l   p r a c t i c e s are very important in the regulation of melt waters.

The effect of cultivation on local runoff was elucidated by a number of authors (Kuznik, 1937; Polyakov, 1939;

Sukharev, 1951, 1957; L'vovich, 1954; Surmach, 1955, and others).

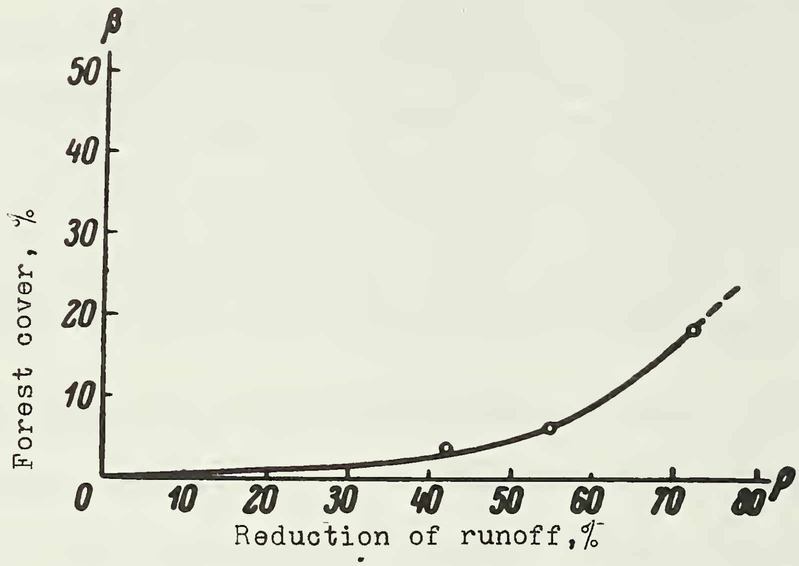

FIG. 2. Reduction in Water Runoff as a Function of the Forest Cover of a Catchment

Our investigations conducted at Kamennaya Steppe showed that on compacted and smooth land - virgin land, winter crops and grasses, runoff is always about 1.5-2.0 times higher than on fields with the soil well loosened by late fall plowing.

On the average for a long-term period of observations (1950-1958) the runoff was least on an unmowed steppe (in a reserve). The average runoff coefficient on fall-plowed land was 0.40. The runoff coefficient on a plot located in a forest belt was 0.08, on winter crops - 0.83, on alfalfa - 0.60, on stubble - 0.58, on unpastured steppes - 0.57, on mowed but not pastured steppe, 0.49.

If the average runoff coefficient on fall-plowed land is taken as unity then the coefficient on the plot located in the forest belt would be equal 0.37, on the winter

crop - 1.85, on alfalfa - 1.5, stubble - 1.3, on grazed steppe - 1.58 and on mowed (ungrazed) steppe - 1.15.

The presented data show sufficiently well that agrotechnics (type of tillage) are one of the important factors affecting the runoff of melt water.

P o n d s a n d r e s e r v o i r s. During the period from 1948 to 1962 a large number of ponds and reservoirs were constructed in the CCP. These ponds were constructed mainly for the purpose of domestic water supply and of irrigation of agricultural crops. A considerable number of the ponds constructed during this period had a volume of 100-300 thousand m^3.

In addition, many large interkolkhoz reservoirs with volumes of from 2 to 4.5 million m^3 were constructed in these provinces in the Talovskiy, Annenskiy, and Elan'-Kolenovskiy Districts of the Voronezh Province; in the Yasrebovskiy and Ivaninskiy Districts of the Kursk Province, and also in other provinces of the CCP. Ponds constructed in the indicated years exerted a considerable water-regulating influence. As of 1 January, 1962 the volume of the ponds expressed in depth of runoff was 1.9 in the Belgorod, 4.9 in the Voronezh, 3.1 in the Lipetsk, 2.8 in the Orel, 4.1 in the Tambov and 2.8 mm in the Kursk Provinces. On the average for the zone it was 3.4 mm.

The increase in the number of ponds and in the volume of water stored in them in the Voronezh Province for a 55-year period (1900-1955) is shown in a graph in Figure 3

in which the number and the volume of the ponds on 1 January, 1955 is taken as 100%. This figure shows that in 1900 there was a small number of ponds with a runoff regulating volume of about 4%. A considerable increase in the number of ponds took place during the period from 1923-1940. But the construction of ponds was most rapid from 1948 to 1955 when the number of ponds in the province increased by 45% and the volume of water in them increased almost 5-fold. During this period ponds and reservoirs of considerable dimensions were constructed for more complete storage of local runoff water and to meet the needs for irrigation. A large amount of work in the construction of ponds and reservoirs was done in the indicated years in the Talovskiy District. This district is now the best watered district in the Voronezh Province and in the CCB as a whole. In this district there are 220 ponds with a total volume of 18.9 million m^3 of water with a water surface of 918 ha.

The ponds of the Talovskiy District retain annually an average of 21.6% of the local runoff water.

Combined Effects on Runoff of Forest Reclamation, and Agrotechnical Practices and also of Ponds and Reservoirs. The combined application of the enumerated practices exert a very strong influence on the reduction of local runoff.

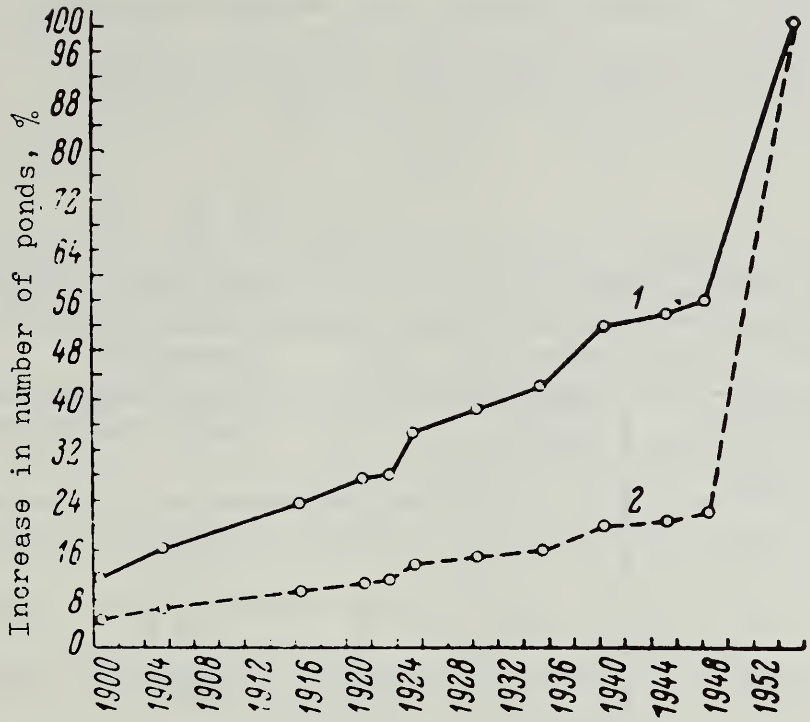

FIG. 3. Increase in the Number of Ponds in the Voronezh Province and in their Total Capacity from 1900-1955.
1 - Number of ponds, %; 2 - Total capacity of ponds, %.

We shall discuss the runoff from the Kamennaya Steppe catchments where the combined influence of Man's agricultural activity on runoff was observed. For this analysis we used runoff data obtained by the Dokuchaev Expedition in 1894 on unplowed catchments and data for the period when the catchments were plowed. Runoff from the catchment of the Ozerki Ravine with a 26.5 km^2 area was 55.7 mm in the Spring of 1894. This entire catchment was at that time in steppe and was used only as pasture and hay land. Its plowing up began only in 1920. The winter of 1893/94 had a stable snow cover and moderate frosts. The snow cover stabilized in the middle of December and remained stable for 140 days. There were no winter thaws. The years 1935/36, 1942/43; 1944/45 and 1949/50 (Table 17) at Kamennaya Steppe

were similar to 1893/94 with respect to meteorological conditions of the fall-winter and the Spring periods (analogue-years).

Table 17

METEOROLOGICAL CHARACTERISTICS OF THE ANALOGUE-YEARS

Analogue-year	Total precipitation, mm		Average air temperature Jan.-March, °C.
	Nov.-Dec. of Previous Year	Jan.-March	
1894	50	28	-8.0
1936	74	34	-7.3
1943	44	21	-9.9
1945	32	22	-10.3
1950	46	42	-9.9

The presented table shows that with respect to meteorological conditions the analogue-years (1936, 1943, 1945 and 1950) are very close to 1894.

Snowmelt runoff from the catchment of the Ozerki Ravine was 55.7 mm in 1894. In 1936, 1943, 1945 and 1950 it was respectively 27, 30.6, 17.6 and 7.9 mm. On the average for the 4 years it was 20.6 mm. The average runoff from the catchment of the Ozerki Ravine for the indicated 4 years was thus 35.1 mm less (2.7 times) than the runoff in 1894. In the upper part of the catchment of the Ozerki Ravine (approximately half of the area) there are forest belts (the forest cover is 9%). There are also 16 ponds with a total volume of nearly 500 thousand m^3 in the Ozerki Ravine. Plowing up of the catchment, the forest belts, and the ponds considerably transformed the runoff from

this catchment. On the average for 24 years (1935-1958) runoff of snowmelt constituted 30.4 mm or 25.3 mm (45.3%) less than the runoff in 1894.

Adjoining the catchment of the Ozerki Ravine is the 24.7 km^2 catchment of the Osinovaya Ravine. The catchments of the Ozerki and Osinovaya Ravines are very similar in size, relief, and in the nature of the soil.

Observations of runoff on the catchment of the Osinovaya Ravine began in 1935, i.e., at the time when the catchment was being plowed up. This catchment is not forested and is under steppe conditions. Surface runoff from this catchment for the analogue years (1936, 1943, 1945 and 1950) was respectively 45.7, 35.6, 35.0 and 37.7 mm. The average for the 4 years was 38.6 mm. Thus, the runoff from the plowed-up catchment of the Osinovaya Ravine was 17.1 mm (30.7%) less than the runoff in 1894 when the catchment was an unplowed steppe. Therefore, the plowing up of the catchment resulted in a considerable reduction of runoff.

Hydrographs for the catchment of the Osinovaya Ravine for 1936, 1943, 1945 and 1950 (analogue-years) and the 1894 hydrograph for the catchment of the Ozerki Ravine are given in Fig. 4. A comparison of these hydrographs shows quite well the reduction in the flow of the Osinovaya Ravine during the period when the catchment was plowed up.

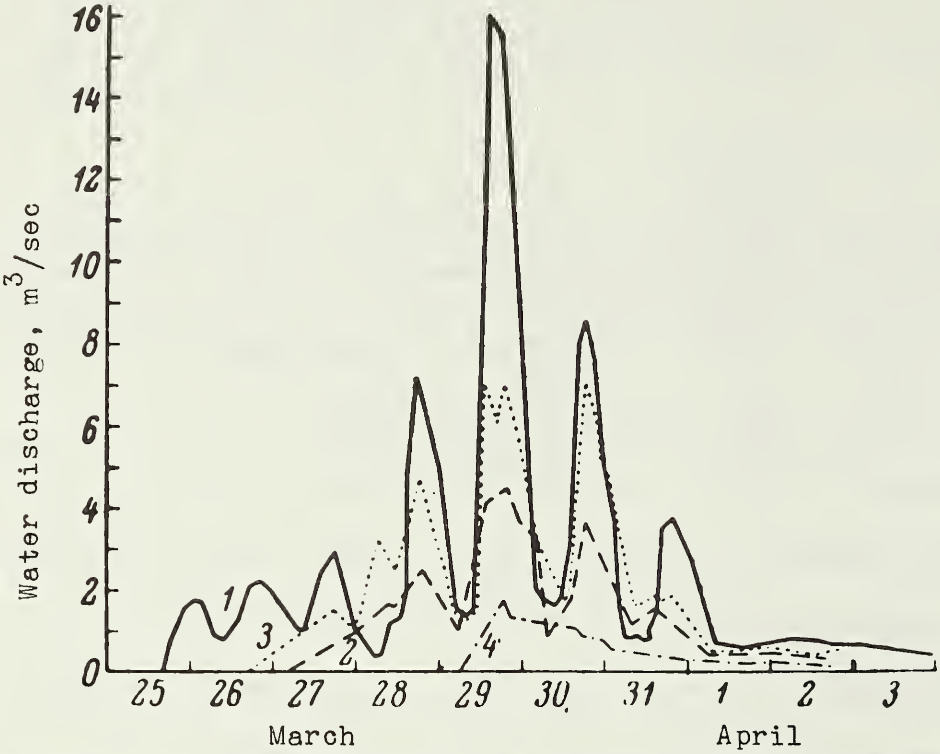

FIG. 4. HYDROGRAPHS OF SPRING RUNOFF FROM THE OZERKI AND OSINOVAYA RAVINES

1 - Ozerki rav., 1894; 2 - Osinovaya rav., average hydrograph for the analogue years (1943, 1945, and 1950); 3 - Osinovaya rav., upper envelope of hydrographs for the analogue-years; 4 - Ozerki rav., the highest hydrograph for the analogue-years.

For the highest flood of the analogue-years (1945) the ordinates of the hydrograph are many times smaller than the ordinates of the 1894 flood hydrograph. Thus the data in Fig. 4 indicate a strong influence of Man's agricultural activity on local runoff; a considerable reduction under the influence of the plowing up of the catchments, of its afforestation, of the construction of ponds, etc.

Flow duration curves (theoretical and observed) of snowmelt for a number of the Kamennaya Steppe catchments: the Osinovaya, Ozerki and the headwaters of the Ozerki Ravine are shown in Fig. 5.

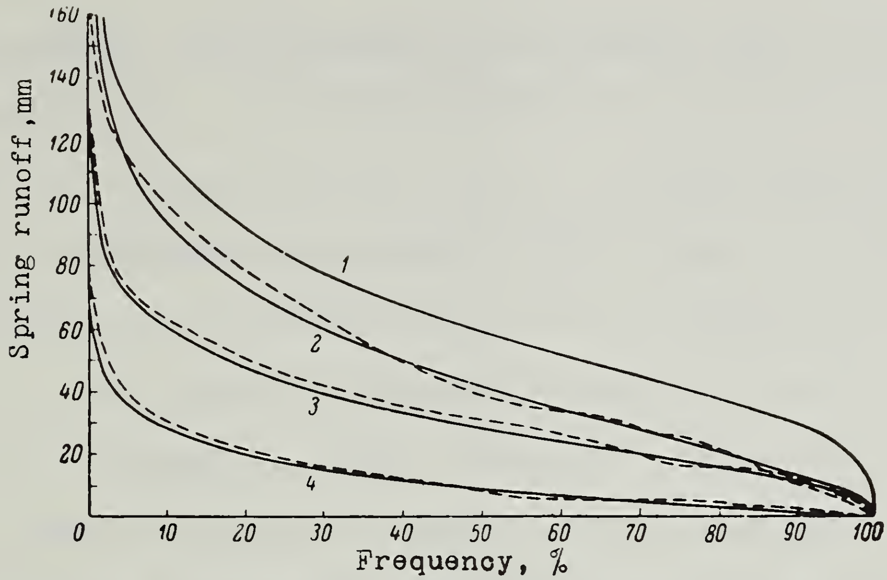

FIG. 5. Duration Curves of Runoff of Melt Waters from the Catchments of the Ozerki and Osinovaya Ravine

1 - Ozerki Ravine, prior to plowing up; 2,3 and 4 - Osinovaya, Ozerki and headwaters of Ozerki Ravines in the present state of the catchments. Dashed lines - according to observation data. Solid lines according to computed data.

As seen above the areas of the above-named three catchments are respectively 24.7, 26.5 and 7.1 km^2. A description of these catchments was given above. Here we shall only note that the catchment of the Osinovaya Ravine is in steppe condition, which are typical for the southeast of the Voronezh Province. The lower part of the catchment of the Ozerki Ravine is under steppe conditions while its upper part (about half of the area) is planted to forest belts. There are on the Ozerki Ravine 16 ponds with a water volume of about 500 thousand m^3. The catchment of the headwaters of the Ozerki Ravine is 9% forested, correct crop rotations are used on the fields. This ravine has 8 ponds with a water volume of about 100 thousand m^3.

All three catchments are similar with respect to soil conditions and the character of the relief. They are intensively cultivated (80-85% plowed up). Plowing on them began in 1920-1922.

Curve 1 (Fig. 5) shows the frequency of snowmelt runoff from the catchment of the Ozerki Ravine prior to plowing. This curve was constructed with data of the 1894 Dokuchaev Expedition (Sukharev, 1957). Curve 2 represents the frequency of the present-day runoff from the catchment of the Osinovaya Ravine. This curve was constructed with runoff data for this catchment for the period 1935-1957, i.e., for the period when the catchment was plowed; it shows how the runoff was reduced under the influence of cultivation. Curve 3 shows the present-day runoff from the catchment of the Ozerki Ravine (observations 1935-1958).

Of great interest is Curve 4 for the catchment of the headwaters of the Ozerki Ravine where runoff was reduced considerably under the influence of Man's agricultural activity (cultivation, correct crop rotations, forest belts, and ponds and reservoirs). The average runoff from this catchment is 9 mm, i.e., 5 times less than the average runoff from the catchments of the Talovskiy District. In determining the runoff from this catchment the runoff retained by the ponds was included.

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A. M. G R E E N*, G. V. NAZAROV

INFILTRATION PROPERTIES OF THE SOILS OF THE CENTRAL CHERNOZEM PROVINCES

A quite large number of experimental investigations of the forming of the water balance of different natural and agricultural areas were carried out in the last ten years in the Central Chernozem Provinces (CCP) and also in the forest-steppe districts of the Ukrainian SSR which adjoin them on the west. However, the comparison and generalization of the obtained material is often made difficult by the differences in methods used in conducting these experiments and by insufficiently accurate description of the experimental conditions. In this connection there arose the need of obtaining data which could serve as objective criteria in the evaluation of conditions of forming of the water balance on the experimental areas.

It seems to us that one such "integral index of conditions" could be the absorption capacity of the soil which determines for each area the relationship between values of infiltration and of surface runoff. With this in mind the authors conducted during 1960-1962 investigations of the absorption capacity of the soil of the majority of the areas in the CCP on which experimental studies of the forming of the water balance were conducted. These investigations covered a considerable part of the forest-steppe zone in the area bounded by the basin of the Bityug River (left tributary of the Don) on the east and by the

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* The correct transliteration is Grin. The name, however, is pronounced Green.

basin of the Ros' River (right tributary of the Dnepr) on the west. The investigated areas included: 1) the Hydrometeorological Observatory of the Hydrometeorological Service "Kamennaya Steppe" (Talovskiy District of the Voronezh Province); 2) the Nizhnedevitskaya Runoff Station of the Hydrometeorological Service (Nizhnedevitskiy District of the Voronezh Province); 3) the Stations of the Institute of Geography, Acad. of Sci., USSR in the in the Ivaninskiy and Streletskiy Districts of the Kursk Province; 4) the Pridesnyanskaya Runoff Station of the Hydrometeorological Service and the Pridesnyanskaya Gulley Station of the Ukrainian Scientific Research Institute of Agroreclamation and Forestry (Ponornitskiy District, of the Chernigov Province); 5) the Boguslavskaya Scientific Research Hydrologic Station* (Boguslav District of the Kiev Province).

The objective of the investigation was not to obtain absolute values of the absorption capacity of the soil of various types of land in the different experimental areas but to obtain data for an objective evaluation and comparison of results of water balance investigations. This predetermined the selection of the method of obtaining these values. With the long distances between investigated areas and the limited time available for carrying out the large number of experiments, this methodology in which strict uniformity was imperative had to be as simple and as dependable as possible. These requirements were met by the long-known

* Of the Institute of Hydrology and Hydrotechnics, Acad. of Sci., Ukr. SSR.

and well-tested method of flooded rings (Astapov and Dolgov, 1959). A detailed description of the methodology used by us as well as a description of the investigated areas on the stations of the Institute of Geography, Acad. of Sci., USSR in the Ivaninskiy and Streletskiy Districts of the Kursk Province were published previously. (Green and Nazarov, 1963) and will therefore not be dwelled on here.

We shall briefly pose to describe the other locations at which our investigations were conducted. The soils of the Kamennaya Steppe area are ordinary chernozems. With respect to the mechanical analysis the soils are clays, silty-clayey, heavy clay loams containing very little sand. The thickness of the organic horizon of the ordinary chernozem is 35-56 cm on the slopes and 55-65 cm on the ridges. The organic matter content in these soils ranges from 6 to 10%. The structure of the plow depth and of the underlying horizons vary depending on the character of land use. The soils in forest belts (90% of water stable aggregates greater than 0.25 mm) and long fallow (80-86% of stable aggregates) occupy the first place with respect to the quantity and quality of the structural aggregates. Cultivated soils contain 55-70% of stable aggregates in the plow layer and 80-82% in the subsoil (D.P.Burkatskiy and I.K.Vinokurova,1951). The structure of the upper part of the plow horizon is less water stable than that of the lower part because it is subjected to weathering and to the action of agricultural machinery.

Data on volume-weights and field capacity of soils of the various experimental areas at Kamennaya Steppe are given in Tables 1 and 2.

TABLE 1

VOLUME-WEIGHT OF SOILS OF DIFFERENT EXPERIMENTAL AREAS AT KAMENNAYA STEPPE, g/cm^3

Depth, cm	Virgin land			Forest belts			Cultivated (Knorol'skaya rav.)
	Grazed	Mowed	Not mowed	№ 74	№ 123	№ 131a	
0—10	1.09	1.00	0.83	0.95	0.94	1.01	0.98
10—20	1.14	1.15	0.90	1.05	1.04	1.01	1.00
20—30	1.22	1.20	0.90	1.08	1.12	1.14	1.03
40—50	1.25	1.26	1.11	1.15	1.16	1.22	1.21

TABLE 2

FIELD CAPACITY OF THE SOILS OF DIFFERENT EXPERIMENTAL AREAS AT KAMENNAYA STEPPE (%)

Depth, cm	Virgin land		Forest belt	
	Mowed	Not mowed	№ 131a	№ 74
0—10	38.8	46.3	33.9	33.6
10—20	31.2	45.2	33.3	32.0
20—30	31.0	34.4	31.8	33.0
40—50	29.5	31.5	31.5	30.0

The forest litter in the forest belts is 2 cm thick in the young belts and 3-4 cm in the old ones. The water-holding capacity of forest litter ranges from 213 to 429% (Bayko and Gorbulenko, 1949).

The area of the virgin land reserve is located on the northern slope of the Talovaya Ravine and is covered by a feather grass-fescue - motley grass plant association (feather grass + sheep's fescue + motley grass). This group and the motley grass - sheep's fescue association are typical also for the hay land and for sod conditions (N.S.Kamyshev, 1956).

The Nizhnedevitskaya Runoff Station is located in the northwestern part of the Voronezh Province not far from the boundary with the Kursk Province. The soil of the station area is ordinary chernozem. The A horizon is 30-50 cm thick with a granular-crumb structure. The mechanical analysis is that of a medium loam. Information on the volume-weight of the soil on the different experimental areas of the Nizhnedevitskaya Station given in Table 3 is based on the data of field investigations carried out by Filipova in 1956.

The Pridesnyanskaya Runoff Station lies beyond the forest-steppe zone but near its northern boundary. Because the station possesses a large amount of runoff data* and its natural conditions are in many respects similar to those of the Chernigov Forest Steppe, the data of infiltration properties of its soils are of considerable interest. The area of the station has a typical gully-ravine relief, with elevations ranging from 180 to 200 m on the watershed divide to 140 m in the valley of the Golovesnya River. The soils are weakly to medium and

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* Observations began in 1949.

TABLE 3

VOLUME-WEIGHT OF SOILS ON DIFFERENT EXPERIMENTAL AREAS OF THE NIZHNEDEVITSKAYA STATION, g/cm^3

Depth, cm	Layland* (Runoff Plot #3)	Stubble** (rav. Malyy Repnyy)	Oak Forest *** (Dolgiy rav.)		Depth, cm	Layland* (Runoff Plot #3)	Stubble ** (rav. Malyy Repnyy)	Oak Forest *** (Dolgiy rav.)	
			Middle slope	Upper slope				Middle slope	Upper slope
0—5	1.10	1.04	0.96	1.00	60	1.01	1.07	1.28	1.10
10	1.10	1.04	0.96	1.00	70	1.07	1.08	1.30	1.14
20	1.01	0.99	1.05	1.08	80	1.03	1.08	1.34	1.17
30	1.03	1.01	1.18	1.06	90	1.07	1.10	1.38	1.24
40	1.04	1.06	1.18	1.06	100	1.12	1.07	1.35	1.30
50	1.06	1.06	1.26	1.08					

* The runoff plot is located on the same slope as runoff plots nos. 15 and 16.
** The pit is located on the southern slope.
*** The pit is located on a northern slope.

strongly podzolized chernozems. The main element of the soil complex are the gray forest soils. A substantial part of the surface (70%) is cultivated, the rest of the area is in meadow, gullies, and in forests. The total forested area of the catchment of the Golovesnya River constitutes only 2% (Onufrienko, 1959).

The surface of the catchment of the Podlyado Ravine is to a considerable extent dissected by a gulley-ravine net. The slopes are smooth and steep. The prevailing slope is 15%*. The permeability experiment was set up on a southwestern slope covered by a sparse oak forest with a poorly developed forest litter. Hay is grown in the areas between the trees. The soils are gray forest underlain by loess-like sandy loams and light loams. Runoff plots No. 8 and 9, with slopes of 12.4% are located on the slope of the Podlyado Ravine.

The catchment of the Lipino Ravine is also highly dissected by a gully-ravine net. The catchment is open, there is no forest. The slopes are predominantly of western exposure. The average slope is 23%. The floor and slopes of the valley are composed of loess-like loams. The experiment was carried out on the slopes of the ravine near the talveg.

The catchment of the Opytnyy Ravine is quite flat. The average slope of the catchment is 2%. The soils are gray forest. The plow horizon is structureless, uniform and is composed of gray silty sandy loam. In

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* The slope of the area where the experiment was carried out (sparsely forested) is equal to about 30%.

the lower part of the catchment* at a depth of 0.3-0.5 m there is a loam layer 0.1-0.5 m thick. The entire area of the catchment is cultivated.

Runoff Plot No. 5 is located in a mature deciduous forest in which aspen and oak predominate. The cover density does not exceed 0.5. The understory (hazel) is well developed. The forest litter reaches a thickness of 2 cm. The grass cover is poorly developed. The soils are gray forest, podzolized, coarse silt. The slope of the plot is 2.5%.

Data on the volume-weight of the soils of some of the experimental areas of the Pridesnyanskaya Station are given in Table 4.

TABLE 4

VOLUME-WEIGHT OF THE SOILS OF THE PRIDESNYANSKAYA STATION, g/m^3

Depth, cm	Runoff plot, No.9	Opytnyy Ravine	Forest Belt
0-5	1.20	1.23	0.87
5-10	1.25	1.25	
10-20	1.38	1.34	1.03
20-30	1.45	1.35	1.16
30-40	-	1.35	1.27
40-50	-	1.35	1.38

The Boguslavskaya Hydrologic Research Station is located in the Ros' River Basin within the Boguslavskiy and Starchenskiy Districts of the Kiev Province, which is part of the southern part of the forest-steppe zone where areas of broad leaf forest are encountered in the prevailing steppe. The relief of the station area is strongly dissected

* Where we conducted the experiment.

by gullies and ravines.

The main part of the forest on the station area consists of decidous trees 50-60 years of age and younger. The principal species are oak and hornbeam. Continuous original plantings are seldom encountered. On forest areas close to inhabited places cattle are grazed with the result that there is almost no forest litter and the structure of the soil differs little from that in open places; in places where cattle roam it approaches the structure of cattle yards and of roads. Therefore, runoff conditions on such forested areas differ little from those of open areas (Shvetz, 1953).

There is no great diversity of soils on the station area. On the elevated watershed divide areas the parent material of the soil is a silty, loess-like loam; and in the valleys and gullies the parent material is glaciated or Poltava fine-grained sands. Medium and low-humid podzolized chernozems 25-45 cm thick are developed on the loess-like loams. The thickness of the soil horizon decreases towards the slopes of the valleys and of the ravines. On steep slopes the entire soil horizon is washed away.

Forest soils formed on strongly eroded podzolized chernozem can be classified as gray, non-calcareous forest soils. On pure sands light-gray sandy soils are developed which are quite poor in organic matter and are usually structureless and are easily dispersed (Drozd, 1956).

Data on the volume-weight of the soils of some of the experimental areas of the Boguslavskaya Station are given in Table 5.

TABLE 5

VOLUME-WEIGHT OF THE SOILS OF THE BOGUSLAVSKAYA STATION, g/m^3

Area	Volume-weight of soil at a depth, cm			Remark
	0	20	50	
Deciduous forest..........	1.22	1.26	1.38	Well developed undergrowth
Pine forest...............	1.10	1.18	1.46	Sandy soil, no litter
Oak forest................	1.30	1.43	1.32	Intensive grazing
A field near a forest belt on the watershed divide between Bashi and Tuniki...	0.98	1.35	1.27	Freshly plowed soil
Ravine at Misaylovki.......	1.32	1.27	1.37	Grazed virgin land

We shall consider the infiltration properties of the soils of the following experimental areas in the selected district: 1) virgin land, 2) cultivated land, 3) forest, 4) forest belt.

In comparing the soils on virgin land (Table 6 and Figure 1) we see that virgin land that is not mowed or grazed has the highest absorption capacity. Next comes the mowed virgin land. During the 150 min. of the experiment the mowed virgin land in the Streletskaya Steppe absorbed about 2/3 to half as much water (418 mm and 265 mm) as the unmowed (606 mm) and at Kamennaya Steppe half as much (504 mm for the mowed and 1002 for the non-mowed). The grazed virgin land has the lowest absorption capacity. The more intensive the grazing on the virgin areas the less their absorption capacity. Thus, during the first

TABLE 6

AMOUNTS AND RATES OF INFILTRATION ON VIRGIN LAND

Location	Soils	Virgin Land	Infiltration	
			In 150 min. mm	Rate mm
Kamennaya Step'	Ordinary heavy-loam chernozem	Unmowed (Since 1882)	1002	5.35
		Mowed	504	2.21
		Grazed	161	0.99
Streletskaya Step'	Deep, typical heavy-loam chernozem	Unmowed	606	3.56
		Mowed (II)	418	2.47
		Grazed (II)	345	1.88
		Mowed (I)	265	1.47
		Grazed (I)	187	1.09
Nizhnedevitskaya Station	Ordinary loamy chernozem	Mowed	298	1.83
		Grazed (Tat'yanin rav.)	123	0.62
Ivaninskiy District	Deep heavy-loam chernozem	Grazed	145	0.70
Pridesnyanskaya Station	Gray forest soils	Grazed (Lipino rav.)	129	0.65
Boguslavskaya Station	Podzolized chernozems (severely eroded)	Grazed	117	0.56

150 min. of the experiment in the Streletskaya Steppe half as much water entered the soil (187 mm) on Area I of grazed virgin land located closer to the inhabited point where grazing was quite intensive than on Area II (345 mm) which is located near a reserve area of the Streletskaya Steppe which is grazed much less frequently.

Soils of the reserve areas of mowed and unmowed virgin land at Kamennaya Steppe have a much higher absorption capacity than those of the Streletskaya Steppe; however, amounts of water entering the soil in the 150 min. of the experiment on intensively grazed areas (161 and 187 mm) are about the same.

Reserve areas of virgin land exist only at Kamennaya Steppe and at the Streletskaya Steppe. Therefore, at the runoff station and also in other placed where we conducted the experiment the designation "virgin land" is somewhat conditional since, while it is not being plowed, it is mowed every year and as a rule, is intensively grazed*.

The amounts of water absorbed by the soils in the 150 min. of the experiment on grazed virgin land turned out to be close on all of our experimental areas and ranged from 117 mm (Boguslavskaya Station) to 145 mm (Ivaninskiy District), in spite of the considerable difference in the character of the soil. This indicated that the deciding factor in the reduction of soil permeability is grazing.

* The Runoff Plot No. 16 at the Nizhnedevitskaya Station where only mowing is done is an exception.

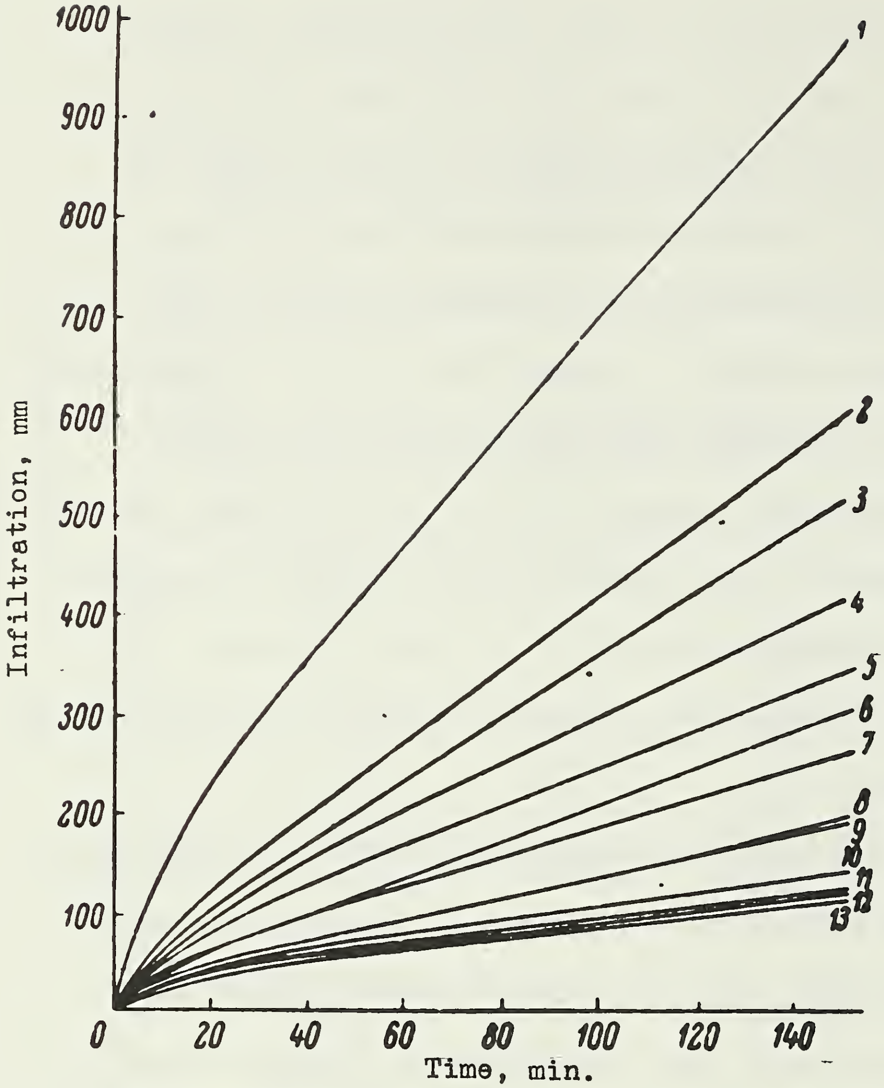

FIG. 1. Mass Curves of Infiltration on Virgin Land

Kamennaya Steppe: 1 - Not mowed, 3 - Mowed, 9 - Grazed. Streletskaya Steppe: 2 - Not mowed (Area I), 7 - Mowed (Area I), 8 - Grazed (Area 1), 4 - Mowed (Area II), 5 - Grazed (Area II). Nizhnedevitskaya Station: 6 - Mowed, 12 - Grazed (Tatyanin Ravine). Pridesnyanskaya Station: 11 - Grazed (Lipino Ravine). Ivaninskiy District: 10 - Grazed. Boguslavskaya Station: 13 - Grazed (Ravine at Vill. Misaylovka).

Observations similar to ours were made at Kamennaya Steppe by I.P.Sukharev (1958) in 1950. Our observations confirm the data obtained by Sukharev who used the Nesterov instrument in his experiments. He performed one experiment on each type of land. We replicated our experiments 3 times.

TABLE 7

COMPARISON OF INFILTRATION DATA ON DIFFERENT TYPES OF LAND OBTAINED AT DIFFERENT TIMES

Type of Land	Total in 150 min., mm		Final rate mm/min.	
	Sukharev	IG AN SSSR*	Sukharev	IG AN SSSR*
Virgin land unmowed (since 1882)	1470	1002	6.3	5.35
Forest belt (60 years old)	546.6	591	2.1	2.57
Mowed virgin land	500.0	504	2.2	2.21

*Institute of Geography Acad. of Sci. USSR

The comparability of I.P. Sukharev (1958) and of our data is shown in Table 7.

The determination of infiltration of cultivated land (Table 8, Fig. 2) is of considerable interest because both Spring and rain surface runoff are formed principally on it. Infiltration was greatest on the chernozem soils (from 166 to 651 mm); that of gray forest soils is much lower (from 34 to 210 mm). Especially notable is the considerable infiltration of the soil with stubble of Sudan grass which considerably increases soil permeability by its highly branched filamentous root system which penetrates to a depth of more than 2-1/2 m. Sudan grass stubble absorbed 3.7 times more water than the adjacent stubble of Spring wheat.

Infiltration on Runoff Plot No. 17 of the Pridesnyanskaya Gully Station was greater (by 20%) than that of the winter-wheat stubble of the Opytnyy Ravine; this is explained by the higher level of agricultural practices at the station where in successfully developing effective means of erosion

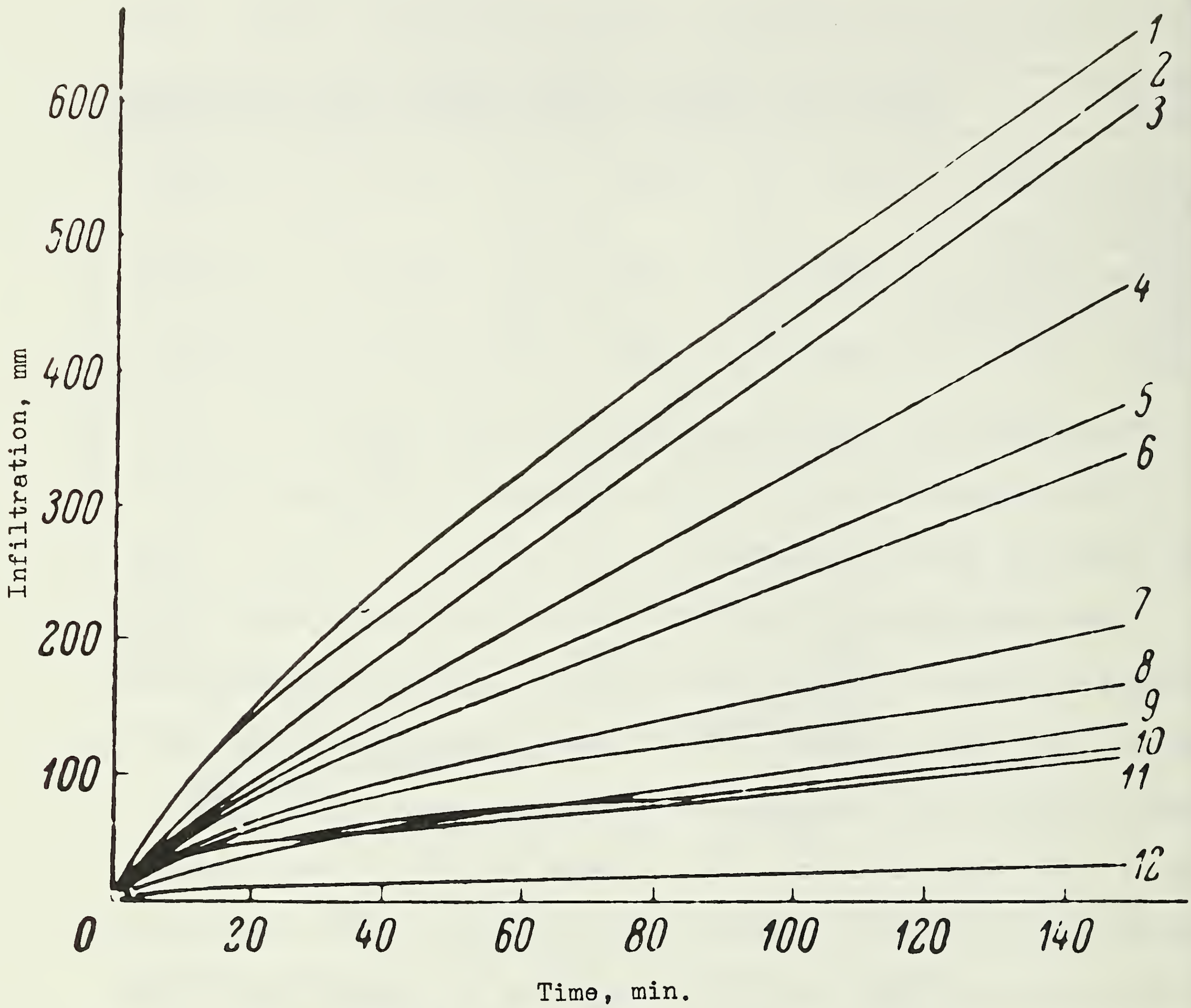

FIG. 2. Mass Curves of Infiltration on Cultivated Land

Streletskaya Steppe: 1 - Rye stubble (an area near the watershed divide of the Golen'kaya Ravine). Kamennaya Steppe: 5- Wheat stubble (Khorol'skaya Ravine); 9 - Perennial grazed grasses (Ozerki Ravine). Ivaninskiy District: 2 - Sudan-grass stubble, 8 - Winter-wheat stubble on chernozem, 12 - Spring-wheat stubble on gray forest soil. Nizhnedevitskaya Station: 3 - Winter-wheat stubble (Runoff Plot No. 15), 4 - Winter-wheat stubble (M. Repnyy Ravine), 6 - Winter-wheat stubble Malyutka Ravine). Pridesnyanskaya Station: 7 - Winter-wheat stubble (Runoff Plots Nos. 8 and 9), 10 - Wheat stubble (Opytnyy Ravine). Boguslavskaya Station: 11 - Wheat stubble.

TABLE 8

AMOUNTS AND RATES OF INFILTRATION ON CULTIVATED LAND (STUBBLE)

Location	Soil	Vegetal Cover	Infiltration In 150 min. mm	Infiltration Rate mm/min.
	Streletskaya Step'			
Upland of Golen'kaya rav.	Deep leached heavy-loam chernozem	Spring rye stubble	651	3.57
Vill. Petrinka (field 5)	same	Barley stubble	498	2.64
	Ivaninskiy Dist.			
Vill. Uspenka	Deep heavy-loam chernozem	Sud. grass stubble	616	3.16
		Spring wh. stubble	166	0.77
Vill. Kolpakovo	Gray forest heavy-loam soils	same	34	0.10
	Nizhnedevitskaya Sta.			
Malyy Repnyy rav.	Ordinary loamy chernozem	Winter wheat stubble	456	2.70
Malyutka rav.	same	same	340	2.12
	Kamennaya Step'			
Khorol'skaya rav. (sodded area)	Ordinary heavy-loam chernozem	"	369	2.30
Ozerki rav. (sodded area	same	Grazed perennial grasses	148	1.08
	Pridesnyanskaya Sta.			
Runoff Plots 8 & 9	Gray forest soils	Winter wheat stubble	210	1.04
Opytnyy rav.	same	same	119	0.57
Runoff Plot 17 (of the gully exp. sta.)	"	Winter rye stubble	148	0.76
	Boguslavskaya Sta.			
Upland between Vill. Tumki and Vill. Bashi	Podzolized chernozems	Winter wheat stubble	105	0.39

control a great deal of emphasis is put on the seeding of lupine. Lupine has a deep root system which penetrates the soil to a depth of 1 m and more and gives high yields of green matter and of roots containing a large amount of nitrogen. When lupine is plowed under it enriches the soil with humus, increases the number of stable aggregates and the porosity, and increases the water-holding capacity and the permeability of the soil (Larin and others, 1951).

The relatively high infiltration observed on Runoff Plots Nos. 8 and 9 is explained by the fact that they are plowed with horse-drawn plows and that the harvest is done by hand*.

Infiltration varies considerably with the elements of the relief (watershed divide, slopes of different exposures, and bottom land). It was, however, established that flat areas of cultivated land near the watershed divides have the highest infiltration; that it is considerably lower on slopes and that the infiltration of soils of areas** near the stream channels and in the valleys is relatively low (Table 9).

The infiltration of the soils of the Pridesnyanskaya Station is relatively low. This is explained by the fact that the soils of the station area contain 65-82% of coarse silt particles and a small amount of sand and clay particles. The small number of colloidal particles cannot

* With tractor plowing, the horizon is strongly compacted by heavy tractor plows. In harvesting the crop, combines compact the surface layers of the soil.

** With a shallow unpronounced channel.

TABLE 9

INFILTRATION OF SOILS IN RELATION TO THEIR POSITION ON THE CATCHMENT

Location	Land Use	Position on Catchment	Infiltration	
			In 150 min. mm	Rate mm/min.
Streletskaya Step'		Ridge area	651	3.57
Golen'kaya rav.	Spring wheat stubble	S.E.slope	187	1.05
		N.W.slope	128	0.64
		Bottom land	72	0.27
Nizhnedevitskaya Sta.	Winter wheat stubble	North slope (gentle)	697	4.20
Malyy Repnyy rav.		South slope (gentle)	216	1.19
Kamennaya Step'	"	Sodded area	369	2.30
Khorol'skaya rav.		Area near channel	142	0.84
Kamennaya Step'	Perennial grasses,grazed	Sodded area	148	1.08
Ozerki rav.		Area near channel	99	0.54

cement the considerable surface of the coarse silt particles. The low clay and humus content of the soils when incompletely saturated with calcium results in a low water stability. After the rain the soils slake easily thus forming a surface crust with poor absorption and infiltration (Skorodumov, 1962).

The same can be said of the soils of the Boguslavskaya Station. They contain 62-65% of sandy and coarse silt (0.1-0.01 mm) and from 2 to 11% of clay particles. This quantity of clay particles is insufficient to cement the large surface of coarse silt and fine sandy particles to form aggregates.

The organic matter content of the soils plays an important role in infiltration. According to the data of Free, Browning and Musgrave (Lindsley et al, 1962) the coefficient of correlation between infiltration and organic matter content of the soil is 0.50, while the correlation coefficient between infiltration and other factors does not exceed 0.36 (with non-capillary porosity). This is well confirmed by our data. The soils of the Kamennaya and Streletskaya Steppes contain considerably more organic matter (6-10% for Kamennaya Steppe and 6.3-8.5% for Streletskaya Steppe) than do the soils of the Pridesnyanskaya (1.1-3.4) and of the Boguslavskaya (5.0, and 2.0% on severely eroded soils) Stations.

Infiltration is highest on forest, especially chernozem soils (Table 10, Fig. 3). Thus, in the forest reserve of the Streletskaya Steppe the soil absorbed

TABLE 10

AMOUNTS AND RATES OF INFILTRATION IN FORESTS

Location	Forest type	Soils	Infiltration	
			In 150 min. mm	Rate mm
	Streletskaya Step'			
Dedov-Veselyy forest	Oak forest	Deep, leached, heavy-loam chernozem	1844	9.50
Dubrashina forest	same	same	1465	6.48
	Pridesnyanskaya Sta.			
Runoff Plot #5	Deciduous forest	Gray forest soils	892	4.56
Podlyado rav.	Thin deciduous forest	same	256	1.45
	Ivaninskiy Dist.			
Bol'shoie Dolgoe Reserve	Deciduous forest	Dark gray heavy-loam forest soils	882	4.87
	Nizhnedevitskaya Sta.			
Dolgiy rav.	Grazed oak forest	Ordinary loamy chernozem	374	1.91
	Boguslavskaya Sta.			
	Oak (with underbrush)	Gray forest soils	238	0.92
	Pine (without underbrush)	same	57	0.23
	Oak (grazed)	"	48	0.20

1400-1800 mm of water in 150 min; on the gray forest soils in the Ivaninskiy District and on the Pridesnyanskaya Station only 900 mm. All these forests are in good condition since there is no grazing and there was no clearing. In these forests there is a thick undergrowth of hazel, the roots of which permeate the soil.

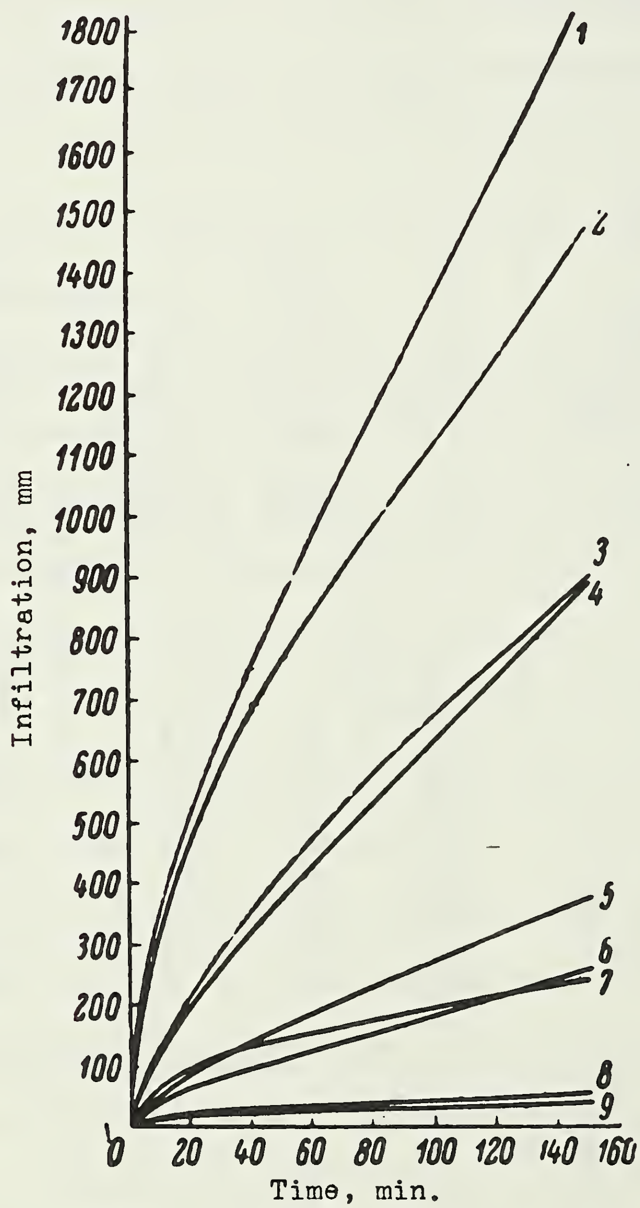

FIG. 3. Mass Curves of Infiltration in the Forest.

Streletskaya Steppe: 1 - Dedov-Veselyy, 2 - Dubrashina. Pridesnyanskaya Station: 3 - Deciduous forests, 6 - Deciduous thin forest. Ivaninskiy District: 4 - Bol'shoe Dolgoe Reservation, Nizhnedevitskaya Station: 5 - Oak forest. Boguslavskaya Station: 7 - Oak forest, 8 - Pine forest, 9 - Grazed oak forest.

Infiltration of forest soils without undergrowth and especially of those that are grazed is quite low. For instance, in the grazed forest on the Dolgoe Ravine of the Nizhnedevitskaya Station only 374 mm of water infiltrated in 150 min. The infiltration in such forests with gray forest soils is even lower (Boguslavskaya Station).

Thus, the forest exerts an enormous influence on infiltration. Infiltration is aided not only by the powerful root system of the trees and of the undergrowth but also by the litter which prevents the silting in of the pores that conduct the water. The pronounced nutty structure of the upper soil horizon and the protective forest litter (the forest reserves of the Streletskaya Steppe, the Bol'shoe Dolgoe Reservation and Runoff Plot No. 5 on the Pridesnyanskaya Station), ensure high infiltration of the forest soil.

In our experiments the flow of water in the vertical root ducts in the forest soil was to a large extent reduced by: 1) the fact that the rings were driven to a depth of 15 cm, so that the more friable layers of the investigated forest soils were isolated and 2) because the rings were driven into the ground at a considerable distance from the trees. This makes it possible to suppose that we selected spots which were least favorable from the standpoint of infiltration and it must therefore be considered that, in general, the infiltration values for a forest soil obtained by us are not too high.

The lower infiltration of the soil under the forest of the Boguslavskaya Station is explained by the fact that these were planted forests (50-60 years and younger). The nutty structure which forest soils have was not formed in them. Undergrowth and a pronounced forest litter exist only in one of the three forests in which we conducted our experiments. Intensive grazing in an oak forest deprives the soil of its characteristic properties. This resulted in the low infiltration of this soil. Of all the investigated experimental areas only wheat stubble and forest belts on gray forest soils near the Vill. Kolpakovo had lower infiltration (48, 34 and 46 mm in 150 min. respectively).

Forest belts exert a considerable influence in increasing infiltration, especially on chernozem soils (Table 11 and Fig. 4). Thus, at Kamennaya Steppe the soil under forest belt No. 123 (planted in 1940) absorbed 515 mm of water in 150 min. while the soil of adjacent grazed virgin land absorbed only 161 mm. In the Ivaninskiy District a 20-year old forest belt on chernozem soils absorbed 394 mm of water, while an adjacent area in Spring wheat stubble absorbed 166 mm.

Forest belts on gray forest soil and on podzolized chernozems have a much lower infiltration capacity. Thus, in the Ivaninskiy District (Vill. Kolpakovo) only 46 mm of water infiltrated in 150 min. in a forest belt (planted in 1948); the infiltration on an adjacent stubble area was even lower - 34 mm. At the Boguslavskaya Station a forest belt of the same age on podzolized chernozem

TABLE 11

AMOUNT AND RATE OF INFILTRATION IN FOREST BELTS

Location of Belts	Year Planted	Soils	Infiltration: Amount in 150 min. mm	Infiltration: Rate mm/min.
		Kamennaya Step'		
Forest Belts No. 131	1949	Ordinary heavy loam chernozem	662	3.45
No. 130	1948	same	660	2.94
No. 74	1908	"	591	2.57
No. 100	1930	"	537	2.55
No. 123	1940	"	515	2.42
		Ivaninskiy District		
Vill. Uspenka	1941	Deep heavy loam chernozem	394	2.08
" Kolpakovo	1948	Dark gray heavy loam chernozem soils	46	0.15
		Boguslavskaya Sta.		
Vill. Tuniki	1948	Podzolized chernozems	113	0.47

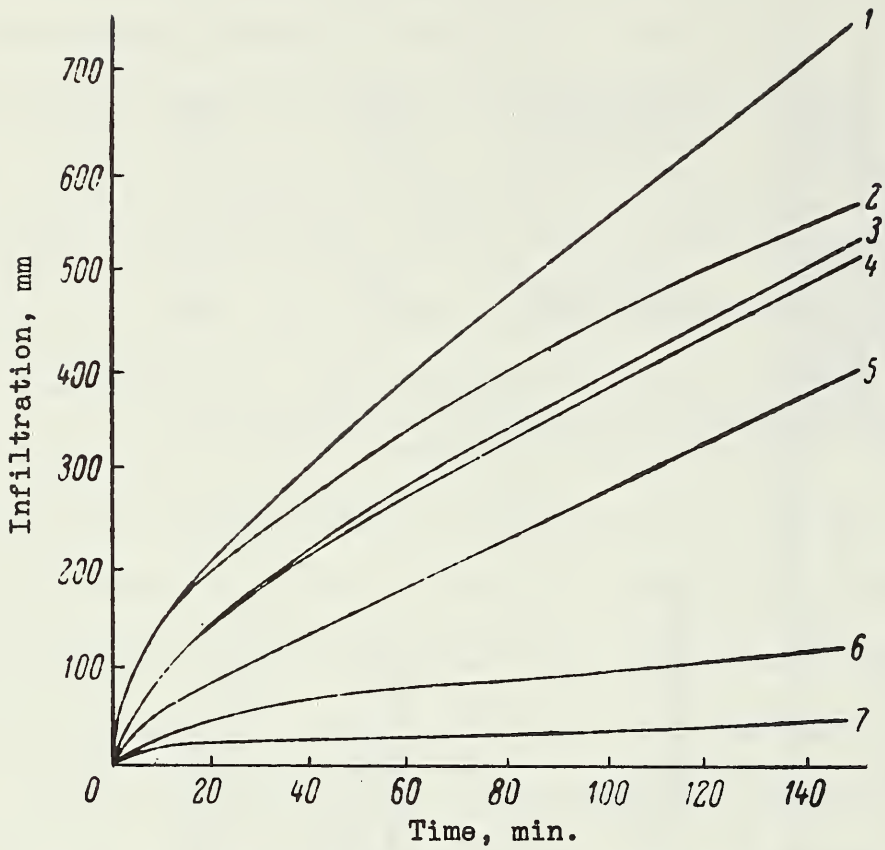

FIG. 4. Mass Curves of Infiltration in Forest Belts

Kamennaya Steppe: 1 - Forest belt No. 130, 2 - Forest belt, No. 74, 3 - Forest belt No. 100, 4 - Forest belt No. 123. Ivaninskiy District: 5 - Forest belt on chernozems, 7 - Forest belt on gray forest soils. Boguslavskaya Station; 6 - Forest belt near Vill. Tunika.

absorbed 113 mm in 150 min. The considerably lower water-absorbing capacity of the forest belt near Kolpakovo is explained by the fact that during the Spring snow melting the soil is strongly silted in by the melt waters running down the slope. The forest belt on the Boguslavskaya Station, however, is located near the watershed divide.

Of the Kamennaya Steppe forest belts the youngest ones (N°N° 130 and 131) absorbed the greatest amount of water. This is explained by the fact that the youngest belts were under the most favorable conditions. Forest

belt No. 130 is located on a slope below belts Nos. 120 and 121, which intercept the runoff from the above-lying fields. The silt from these fields accumulates in the latter belts and plugs the pores of their soils. The lower-lying forest belt receives neither snowmelt nor intense rain water. Forest belt No. 131 lies on a slope and is bounded on both sides by roads so that runoff from adjoining areas does not enter into the belt. In addition, this forest belt is in excellent conditions.

The older forest belts (Nos. 74, 100 and 123) have a lower infiltration capacity because up-slope from them lie cultivated areas. Moreover Belt No. 100 is grazed. These three belts nevertheless show that, other conditions being equal, the infiltration of forest belt soils increases with the age of the belts.

Soil permeability in the CCP was studied by N.V. Sozykin (1940), G.A. Kharitonov (1940), and L.A. Mamanina (1952). N.F. Sozykin did his work in the "Shipov Les" (Buturlinovskiy District in the Voronezh Province) both on forested and cultivated land. On forest land with dark gray forest soils 165 mm infiltrated in one hour*, on gray forest soils only 150 mm. On cultivated land the following values were obtained: on ordinary chernozem - 136 mm, on leached chernozem - 112 mm, and on calcareous chernozem, 79 mm.

All soils of the "Shipov Les" District, both forest and fields, are heavy loams.

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* The experiments lasted only one hour.

The work of G.A.Kharitonov (1940) carried out on dark gray forest loam soil on the Mokhovskiy forest farm (Orel Province) in plantings of different species of trees (Table 12) is of great interest.

The experiments were replicated 3-4 times. The area of the flooded frame was 5 m^2. The frames were pushed into the soil to a depth of 15 cm. The constant water layer above the soil surface was 3 cm.

Comparing our data and those for the Mokhovskiy forest farm and for the "Shipov Les"* we conclude that of the dark forest soils, the soils of the Ivaninskiy District have the highest infiltration (400 mm of water was absorbed in 60 min.). Then come the soils of the Mokhovskiy forest farm (284 mm) and the last are the soils of "Shipov Les" (165 mm).

The considerable amount of work done by L.F.Mamanina (1952) on the Kursk, Orel and Tambov ZOMS** resulted in comparative characteristics of the permeability of the soils of these stations*** (Table 13). The author used 30 x 30 cm^2 frames which were cut into the soil to a depth of 2-3 cm. The constant head of water maintained above the soil surface was 4 cm.

* It should be kept in mind that this comparison is qualitative rather than quantitative because although the experiments were conducted with the same method there were differences in the sizes of the flooded areas in depth of insertion of the frame, etc.

** Zonal Irrigation - Reclamation Station.

*** Regrettably, these experiments were conducted on fields in different crops which makes it difficult to compare the permeability of these soils.

TABLE 12

PERMEABILITY OF SOIL OF THE MOKHOVSKIY FOREST FARM IN DIFFERENT PLANTINGS

Planting	Age years	Infiltration, mm	
		in 60 min.	in 150 min.
Oak	65	284	427
Linden	65	274	389
Larch	75	234	345
Birch	70	198	324
Spruce with pine	70	184	270

TABLE 13

PERMEABILITY OF VARIOUS SOILS ON THE ZONAL STATIONS OF THE CENTRAL CHERNOZEM PROVINCES (MAMANINA, 1952)

Zonal Irrig. Recl. Sta.	Soil type	Experimental Area	60 min. Infiltration, mm
Tambov	Typical chernozem	Cont.cultiv.	235
	Leached chernozem	same	203
Orel	Dark gray forest	--	178
	Gray forest	--	53
Kursk	Leached chernozem	Spring wheat	130
	Weakly calcareous chernozem	Winter rye	70

A comparison of the land of the zonal stations shows that infiltration is highest on the soils of the Tambov Station, next come the dark gray forest soils of the Orel Station, and the leached chernozem of the Kursk Station. The weakly calcareous chernozem (winter rye) of the Kursk Station and the gray forest soils of the Orel Station have the lowest infiltration.

A comparison of the experimental data for the soils of the CCP shows that chernozem soils have the highest infiltration capacity and the light gray forest soils have the lowest. The greatest beneficial effect on infiltration is exerted by the forest and the vegetal cover of virgin land areas. Grazing by cattle greatly impairs the infiltration properties of the soils both on cultivated land and in the forest. Forest belts exert a considerable beneficial influence on the soil by increasing its infiltration capacity.

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I. N. SOROKIN

ELEMENTS OF THE WATER BALANCE OF SMALL RESERVOIRS OF THE CENTRAL CHERNOZEM PROVINCES

There is, now, a large number of small reservoirs in the Central Chernozem Provinces (CCP) which became an integral part of the geographical landscape of the territory. Yet, their hydrological regime, and particularly their water balance, has been poorly investigated.

The general equation of the water balance for reservoirs has the following form:

$$X + Y_{si} + Y_{gr} - Y_{s.d} - Y_{sif} - Y_{i.d} - S - Z = \pm U,$$

where X - precipitation on the reservoir surface, Y_{si} - surface water inflow, Y_{gr} - ground water inflow, $Y_{s.d}$ - spillway discharge, Y_{sif} - siphon discharge, $Y_{i.d}$ - irrigation diversion, S - seepage, Z - evaporation, U - change in the volume of water in the reservoir. All the values are in millimeters or in cubic meters.

For individual reservoirs some of the elements of the water balance may not appear, for instance, Y_{gr}, $Y_{i.d}$, and S. For reservoirs built for complete regulation of runoff (i.e., without spillways) $Y_{s.d}$ will be eliminated.

Inflow of Surface Water

Surface water inflow is the principal incoming part of the balance of the majority of reservoirs. But there are few direct observations of local runoff and they are entirely insufficient to apply over the entire territory of the CCP.

Therefore, an idea of the distribution of local runoff can be gotten from the value of Spring surface runoff of medium and partly of large rivers. It is this only possible approach that was used in the investigation of K.P.Voskresenskiy

who constructed a map of average Spring surface runoff first for the CCP (1948) and later for the steppe and forest steppe zone of the European Part of the USSR (1951) and by V.N.Parshin and M.S.Salov (1955) who constructed a similar map for the Don River Basin.

Beginning in 1946-1958 a network of gaging stations on small rivers of the CCP began to develop and some data have now accumulated which can be utilized in the analysis of the water regime of small streams.

It is of interest to determine to what extent the data of direct observations of flow of small rivers agrees with the runoff map based on data for medium and partially large rivers.

One of the principal problems in planning reservoirs is the determination of normal flow of watercourses feeding the reservoir. On small rivers of the considered territory Spring runoff constitutes an important part of the annual runoff. In order to determine the long-term characteristics of Spring flow we utilized nearly 60 observation points on streams with catchment areas ranging from 1 to about 800 km^2 located in the CCP. The values of flow were determined by planimetering hydrographs of daily discharges constructed with data of hydrological yearbooks. On the hydrographs the ground water feeding was cut off by a straight line drawn from the point of rapid increase of discharge to the point of inflection on the recession leg of the hydrograph.

To verify the validity of the obtained data it is necessary to evaluate the extent to which the years of observations for which streamflow data are available are representative of the long-term variations of flow in the CCP. This task can be resolved by using the residual-mass curve of the runoff coefficient. A description of this method and recommendations for its practical application are given by V.G.Andreyanov (1957).

The CCP are an extensive area. Therefore, several mass curves were used in determining the variation of flow in its various parts. As is known, there are no long records on small rivers. We are therefore forced to resort to data for medium and large rivers.

The river net of the CCP comprises the basins of the Don, Dnepr and Volga Rivers. To represent the variations in flow on the territory of the Dnepr Basin (Kursk and Belgorod Provinces) we used the residual-mass curves of the Desna River at Chernigov constructed by V.G.Andreyanov (1957) and extended by us to 1959 inclusive. For the Volga River Basin (the basin of the Upper Oka - Orel Province) we used the residual-mass curve of the Oka River at Orel constructed by V.G.Andreyanov (1957) and extended by us to 1959. For the Tsna River Basin (Tambov Province) we constructed a residual-mass curve of the Tsna River at Knyazhevo (Fig. 1).

For the vast area of the Don River Basin we constructed a residual-mass curve of the Don at Kazanskaya. This gaging section is representative of the entire basin of the Don River in the CCP (Parshin and Salov, 1955). Observations on small rivers in the basin of the Upper Oka (Orel Province) began in the main in 1950. According to the residual-mass curve of the Oka River at Orel, the runoff coefficient (K) for the period 1950-1959 is close to unity which corresponds to a flow close to the long-term average. Observations on other rivers of this region which are of shorter duration were converted (by means of regression curves) to a ten-year period (1950-1959). Thus, this period can be considered representative with respect to flow.

In the Tsna River Basin streamflow data are available beginning with 1946 (Dvoynya River at Ostroukhovo) and for the Karian River at Sergeevka from 1948. On the remaining rivers observations of streamflow began after 1950. The variations of flow were estimated from the

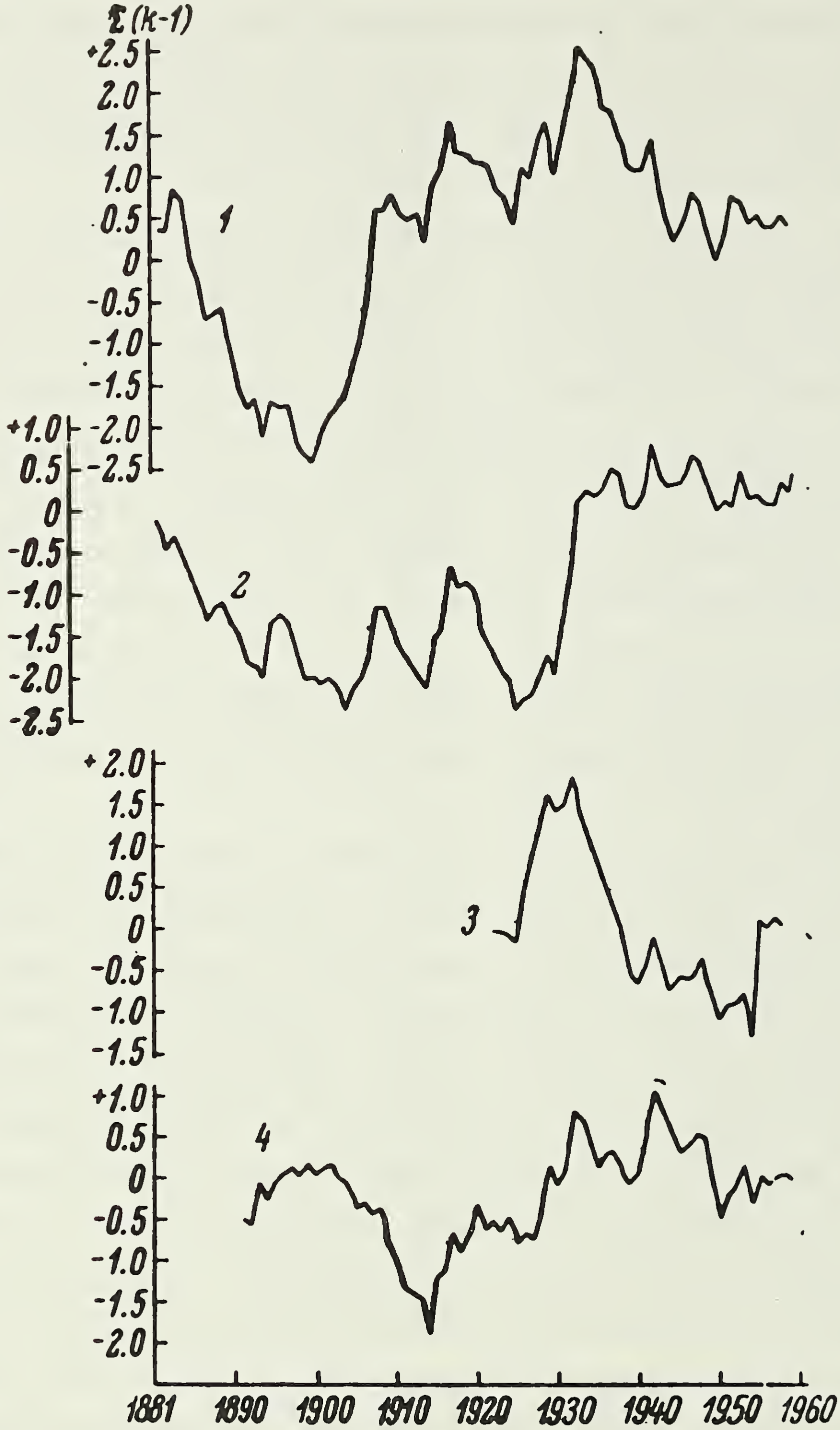

FIG. 1. Residual-Mass Curves of Annual Runoff Coefficients of Rivers in the Central Chernozem Provinces

1 - Oka River at Orel; 2 - Desna River at Chernigov; 3 - Tsna River at Knyazhevo; 4 - Don River at Kazanskaya

Tsna River at Knyazhevo. With the available short records it is difficult to prepare a representative chronological array for which the flow would be approximately equal to the normal. The period 1949 to 1959 is the closest to the long-term average. The coefficient for this period is 1.035 i.e., only 3.5% greater than the normal.

It is necessary to note that this period includes the exceptionally wet year 1955 (K=2.42). The available arrays for small rivers were converted to this period. On the Chelnovaya River at Lysye Gory observations were made from 1927 to 1936. It is interesting to note that the coefficient for this decade is 1.05 i.e., the flow for this period can also be taken as a mean long-term value.

The first meager data on the flow of small rivers in the Seym River Basin were obtained in 1946. According to the residual-mass of the Tsna River at Chernigov the 1945-1959 period has a value of K=0.993, i.e., only 0.7% less than the normal. However, for most of the gaging sections observations are available only from 1949 to 1951. In view of this, the adopted computation period was from 1950 to 1959 and the shorter arrays were converted to this 10-year period which had a coefficient of 0.994. For two gaging sections - Sula River at Zelenkovka and Esman' River at Rotovka, data are available also for the 1932-1940 pre-war period. The period from 1934-1940 with the coefficient K=0.99 is representative for the indicated years.

In accordance with the residual-mass curve of the Don River at Kazanskaya the period 1950-1959 inclusive with K=1 was taken as the representative one for the Don River Basin.

It is necessary to note that the results of this analysis are somewhat approximate for the following reasons.

1. The residual-mass curves were constructed for gaging sections with considerable drainage areas, yet runoff from small catchments may sometimes not agree with

that from large drainage areas. It is, however, true that a special examination of the flow of the rivers of the Seym River Basin showed that the values for all gaging sections were quite synchronous and were also synchronous with the flow of the Tsna River at Chernigov.

2. The used mass curves were for annual instead of Spring flow (this was done only because values of Spring surface runoff for recent years were not computed and it was impossible for us to make these computations). But considering that the Spring flow for this territory constitutes 60% and more of the annual flow, this cannot lead to important errors.

Average depths of Spring runoff derived for the selected representative calendar period are given in Table 1.

In this paper we refrained from extrapolating the available records too far because long records on small rivers are not available as yet and extrapolation of the actual record on a small river by correlation with the flow of medium rivers can lead to the masking of the characteristics of the flow of small rivers. Lengthening the records for small rivers by including the war years (1941-1945) and partially the pre-war period can lead to errors also because the conditions of agricultural development of the catchment areas were different during these periods. For instance, the mean long-term value of flow of the Esman' River at Rotovka for the pre-war period was 73 mm while for the period beginning in 1946 it was only 57 mm. According to I.P.Sukharev's (1960) data for the Osinovaya Ravine (Kamennaya Steppe) the normal runoff from 1936 to 1958 was 48 mm but if the 1950-1958 period is used, then the average runoff reduces to 37 mm. If one considers that the majority of existing ponds in the CCP were constructed after 1948, then it is clear that the average flow of small rivers and of intermittent watercourses for the post-war period is the one that is of the greatest interest.

Table 1

AVERAGE DEPTH OF SPRING SURFACE RUNOFF OF SMALL RIVERS AND OF INTERMITTENT WATERCOURSES OF THE CChP

River, point	F, km²	Period of record	Number of years of record	Av. depth of runoff, mm		Depth of runoff according to K.P.Voskresenskiy's map, mm	Difference between local runoff and Voskresenskiy's map values		Runoff depth by L.G.Onufrienko's map, mm	Difference between local runoff and Onufrienko's map values	
				For period of record	Reduced to 1950-1959		mm	%		mm	%
UPPER OKA PHYSICO-GEOGRAPHICAL REGION											
Oka at Venderovo	513	1952—1959	8	64	62	82	—20	—24.4			
Kroma at Cherkaskaya . . .	853	1952—1959	8	58	56	79	—23	—29.1			
Tson at Novolunie	689	1950—1959	10	73	73	79	—6	—7.6			
Rybnitsa at Lyubanovo . .	709	1952—1959	8	74	71	84	—13	—15.5			
Orlitsa at B. Rog	96	1950—1959	10	67	67	80	—13	—16.3			
Metsnya at Mtsensk	21.1	1951—1955	5	69	57	87	—30	—34.5			
Cherepet' at Svoino . . .	117	1952—1959	8	116	—	100	+16	+16.0			
Cherepetka at Zyabrevo . .	222	1952—1959	8	100	—	100	0	0.0			
							Average	—21.0			
SUDZHANKIY REGION											
Kur at Kazatskaya	61	1946—1959	14	89	89[1]	77	+12	+15.6			
Usozha at Fatezh	364	1948—1959	12	67	67	78	—11	—14.1			
Fatezhik at Fatezh . . .	12.2	1952—1955	4	152	143	78	+65	+83.5			
Svapa at Loktionovo . . .	419	1951—1959	9	73	71	78	—7	—9.0			
Prut at Shirokovo	530	1948—1959	12	58	58	72	—14	—18.0			
Dublyanka at Ryl'sk . . .	12.3	1951—1955 .	5	103	65	66	—1	'—1.5			
Tsvetovo at Tsvetovo I .	20.5	1951—1953, 1959	4	57	37	75	—38	—50.6			
Vorsklitsa at Mokraya Orlovka	612	1956—1959	4	54	50	55	—5	—9.1	55	—5	—9.1
Sula at Zelenkovka . . .	427	1932—1940	9	60	63[2]	52	+11	+21.1	60	+3	+5.0
" " . . .	427	1944—1959	16	61	64[3]	52	+12	+23.1	60	+4	+6.6
Eman' at Rotovka	628	1936—1940	5	73	73[4]	68	+ 5	+7.4	70	+3	+4.3
		1944—1959	16	53	57[5]	68	—11	—16.2	70	—13	—18.5
							Average	—9			

Table 1 (continuation)

River, point	F, km^2	Period of record	Number of years of record	Av. depth of runoff, mm: For period of record	Av. depth of runoff, mm: Reduced to 1950-1959	Depth of runoff according to K.P.Voskresenskiy's map, mm	Difference between local runoff and Voskresenskiy's map values: mm	Difference between local runoff and Voskresenskiy's map values: %	Runoff depth by the map of V.N.Parshin and M.C.Salov, mm	Difference between local runoff and the Parshin-Salov map values: mm	Difference between local runoff and the Parshin-Salov map values: %
SOSNINSKIY REGION											
Grunets at Gagarinskie Khutora	50	1936—1940	4	53	—	85	—	—			
Rakovka at Ratanovka	364	1936—1941	5	65	—	85	—	—			
Sosna at Ivan' 2nd	276	1955—1959	5	92	87	89	—	—2.2	72	+15	+21.0
Livenka at Vorotynsk	83	1956—1959	4	88	—	90	—	—	73	—	—
B. Chernava at Berezhki	523	1954, 1956—1959	5	34	—	90	—	—	73	—	—
Artibya at Berezhki	2.49	1952—1955	4	84	—	90	—	—	73	—	—
TIMSKIY REGION											
Rat' at Ozerki	61	1947—1959	13	67	67[6]	84	—17	—20.2	—		
Rat' at Besedino	615	1948—1950 1953—1959	10	43	58[7]	80	—22	—27.4	—		
OSKOLO-DONETSKIY REGION											
Oskolets at Oskol	494	1952—1959	8	54	52	66	—10	—15.1	—		
Vezelka at Belgorod	394	1947—1959	13	73	73	55	+18	+32.7	—		
Nezhegol' at B. Troitskoe	263	1955—1956, 1959	3	70	—	56	—	—	—		
Lopan' at Kazach'ya Lopan'	189	1956—1959	4	53	—	52	—	—	—		
PRIDONSKIY CHALK REGION											
Veduga at Akulovo	180	1949—1950 1953—1954 1956—1959	8	56	76	92	—16	—17.4	65	+13	+20.0
Devitsa at Nizhnedevitsk	76	1948—1959	12	56	64	92	—28	—30.5	62	+2	+3.0
Yasenok Creek at Nizhnedevitsk	21.7	1949—1959	11	45	45[8]	92	—47	—51.0	62	—17	—27.4
Barsuk Creek at Nizhnedevitsk	10.7	1949—1959	11	53	57	92	—35	—38.0	62	—5	—9.0
							Average	—34.2		Average	—3.2

T a b l e 1 (continuation)

River, point	F, km²	Period of record	Number of years of record	Av. depth of runoff, mm: For period of record	Av. depth of runoff, mm: Reduced to 1950-1959	Depth of runoff according to K.P.Voskresenskiy's map, mm	Difference between local runoff and Voskresenskiy's map values: mm	Difference between local runoff and Voskresenskiy's map values: %	Runoff depth by the map of V.N.Parshin and M.C.Salov, mm	Difference between local runoff and the Parshin-Salov map values: mm	Difference between local runoff and the Parshin-Salov map values: %
K A L I T V I N S K I Y R E G I O N											
Rossosh' at Podgornoe	457	1956—1959	4	42	—	—	—	—	45		
K A L A C H S K I Y R E G I O N											
Osered at Buturlinovka	581	1947—1959	13	50	50	58	—8	—13.8	48	+2	+4.2
T S N I N S K I Y R E G I O N											
Kersha at Pakhotnyy Ugol . . .	613	1952—1959	8	72	66[9]	90	—24	—26.6			
Pilava at Knyazhevo	35	1952—1955	4	88	69[10]	88	—19	—21.6			
C E N T R A L F L A T R E G I O N											
Plavitsa at Bogoroditskoe . . .	782	1957—1958	2	56	—	72	—	—	70		
Usman' at Usman'	236	1949, 1955,	5	50	—	64	—	—	68		
		1957—1959				66	+12	+18.2	65	+13	+20.0
Khava at Il'inovka	426	1951—1959	9	82	78						
N O R T H E A S T E R N P R I T S N I N S K I Y R E G I O N											
Karian at Sergeevka	516	1948—1950	11	79	70[11]						
		1952—1959				84	—14	—16.7			
Chelnovaya at Pudovkino	323	1955—1959	5	114	110[12]	87	+23	+26.5			
Chelnovaya at Lysye Gory . . .	466	1927—1936	10	99	99[13]	89	+10	+11.2			
Dvoynya at Ostroukhovo	106	1946—1959	14	121	121[14]	87	+34	+39.1			
S O U T H E R N B I T Y U G O - K H O P E R S K I Y R E G I O N											
Karachan at Aleshki	565	1952—1959	8	70	68	79	—11	—12.5	55	+13	+24.0
Shpikov at Aleshki	10.1	1952—1953	2	132	—	79	—	—	55		
Ozernyy at Verkhnyaya Orlovka	61.6	1954—1959, 1952	7	46	—	58	—12	—	52		
Kleshnya at Rakitino	58	1951—1959	9	90	84	82	+2	+2.4	65	+19	+29.0

T a b l e 1 (continuation)

River, point	F, km^2	Period of record	Number of years of record	Av. depth of runoff, mm: For period of record	Av. depth of runoff, mm: Reduced to 1950-1959	Depth of runoff according to K.P.Voskresenskiy's map, mm	Difference between local runoff and Voskresenskiy's map values: mm	Difference between local runoff and Voskresenskiy's map values: %	Runoff depth by the map of V.N Parshin and M.C.Salov, mm	Difference between local runoff and the Parshin-Salov map values: mm	Difference between local runoff and the Parshin-Salov map values: %
Tokay at Rostoshi	598	1954—1959	6	61	60	80	—20	—25.0	65	—5	—7.7
Repnyy at Krasnorechenka	33.5	1952—1955, 1957—1959	7	133	123	69	+54	+78.4	52	+71	+136.0
Vysokaya Ravine at Closing Section .. .	0.66	1950—1959	10	29	29	45	—16	—35.6	52	—23	—44.0
Travopol'naya Ravine at Closing Section	0.96	1950—1959	10	34	34	45	—11	—18.3	52	—18	—35.0
Stepnaya " " " "	1.92	1950—1959	10	28	28	45	—17	—37.8	52	—24	—46.0
Berezovaya " " " "	113	1951—1958	8	36	35	60	—25	—41.7	52	—17	—33.0
Talovaya " " " "	90	1951—1959	9	34	34[15]	60	—26	—43.4	52	—18	—35.0
N. Kamenka " " " "	35	1950—1958	9	42	42[16]	60	—18	—30.0	52	—10	—19.0
Osinovaya " " " "	24.7	1935—1958	24	48	37[17]	60	—23	—38.0	52	—15	—29.0
Khorol'skaya " " " "	17.5	1951—1958	8	31	30[18]	60	—30	—50.0	52	—22	—42.0
St. Dubovo " " " "	15.6	1951—1958	8	37	35[19]	60	—25	—42.0	52	—17	—33.0
							Average	—37.0			
EASTERN VORONO-TSNINSKIY REGION											
B. Lomovis at Rozhdestvenskoe.	116	1955—1959	5	100	87[20]	89	—2	—2.5			
Nameless Creek at Chutanovka	20.3	1952—1959	8	175	175[21]	88	+87	+99.0	73	+102	+117.0
MID-KHOPER REGION											
Ol'shanka at Krepovskiy	116	1948—1959	12	49	50	58	—8	—13.8	48	+2	+4.0
SOUTHERN-KALACH LEFT BANK REGION											
Kriusha at Kriusha	668	1951—1953 1956—1959	7	55	42	53	—11	—20.8	35	+7	+20.0
Peskovatka at Shumilinskaya	474	1951—1959	9	64	59	53	+6	+11.3	35	+24	+68.5

R E M A R K. The gaging sections used in deriving long-term means of runoff must be considered as reference sections.

Average runoff is for periods: [1,3,5] 1946-1959, [2] 1934-1940, [4] 1936-1940, [6-7] 1947-1959, [8] 1949-1959, [9,10-12,14,20,21] 1949-1959, [13] 1927-1936, [15-19] 1950-1958

As is known, runoff from small catchments reflects the entire complex of physical-geographical factors and is local (surface) runoff in the full sense of the word (Voskresenskiy, 1951). Therefore, the analogue method of establishing runoff normals can be used only within individual regions with similar physical-geographical conditions. Such regions for the CCP should be determined from the physical-geographical zoning done by the staff of the Voronezh University under the direction of F.N.Mil'kov (1961) (Fig. 2).

The Upper Oka physical-geographical region is relatively well covered by observations. A comparison of the depth of runoff obtained by us with that given in K.P.Voskresenskiy's (1956) map of Spring surface runoff shows that the map gives a higher depth of runoff. On the average for the region the discrepancy between our values and those given in Voskresenskiy's map is 21%. The depth of runoff within the region ranges approximately from 60 to 70 mm. We were unable to disclose any clear regularity in the distribution of runoff within this region.

The Sudzhanskiy Region includes parts of the Kursk and of the Belgorod Provinces. Here the average discrepancy between flow of small streams and Voskresenskiy's map is 9%. For individual gaging sections (Kur River at Kazatskaya; Fatezhik Creek at Fatezh) our computed values are higher than those of the map. This is apparently due to the considerable dissection of these catchments and to transport of snow by wind into ravines which leads to an increase in the snow accumulations. This probability is confirmed by the fact that the catchments are at right angles to the southwestern winds which prevail in the winter (Tsvetkova, 1960).

Moreover, the period of record on Fatezhik Creek is too short (5 years) which could also result in an error

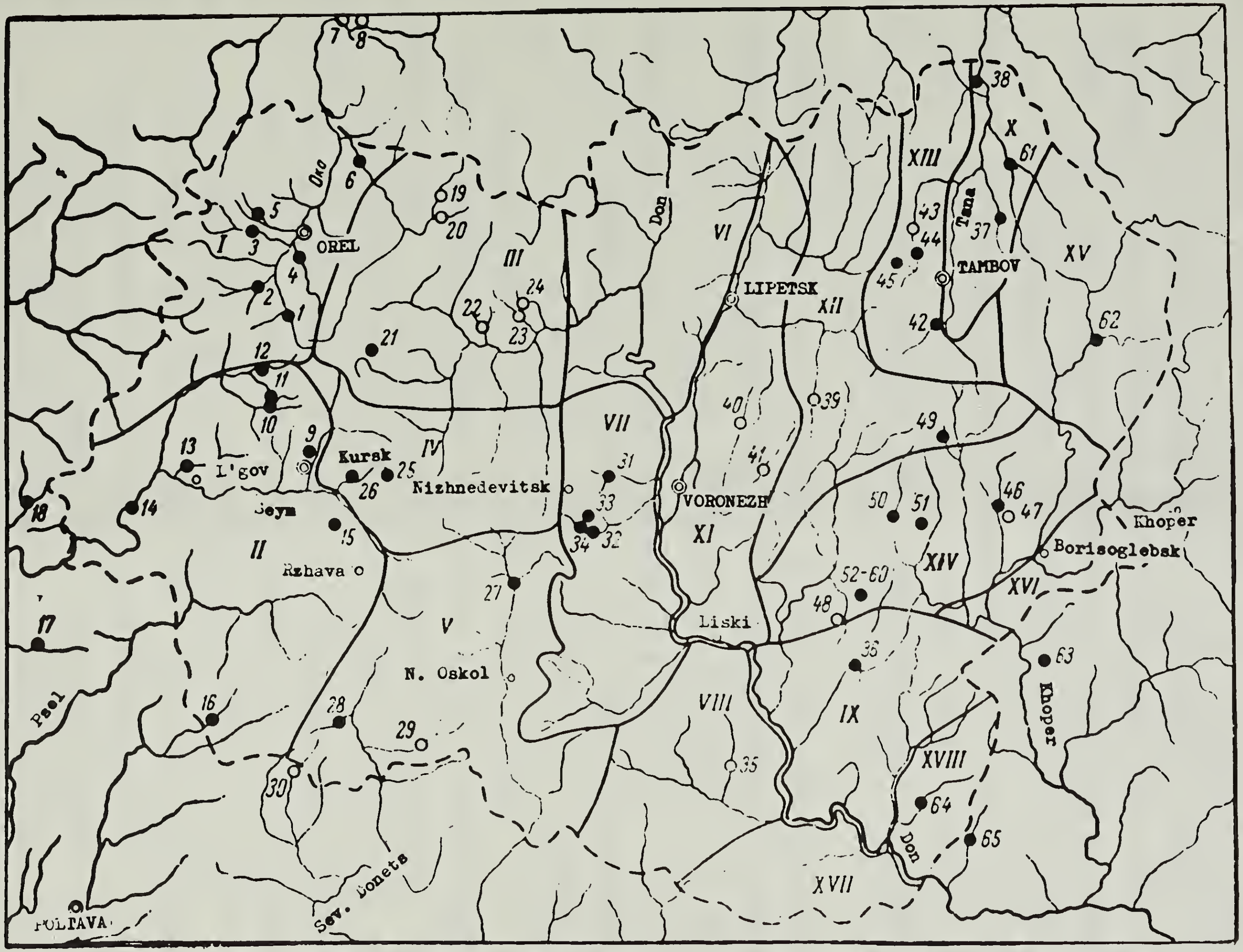

FIG. 2. **Physical-Geographical Regions of the Central Chernozem Provinces (after F. N. Mil'kov) and Location of Gaging Stations on Small Rivers and on Intermittent Watercourses.**

Dots indicate gaging stations used in conversion to long-term mean runoff, circles show stations for which runoff is given for the period of record. Regions: I - Verkhneokskiy, II - Sudzhanskiy, III - Sosninskiy, IV - Timskiy, V - Oskolo-Donetskiy, VI - CisDon limestone-karst, VII - CisDon chalk, VIII - Kalitvinskiy, IX - Kalachskiy, X - Tsninskiy Dolinno-zandrovyy, XI - Left bank, first terrace, XII - Central flat, XIII - Northeastern. XIV - Southern Bityugo Khoperskiy, XV - Eastern Vorono-Tsninskiy, XVI - Middle-Khoper, XVII - Bogucharskiy right bank, XVIII - Southern Kalach left bank.

in extrapolating the record. For three rivers - Sula, Esman' and Vorsklitsa located on the boundary between the CCP and the Ukraine, it is possible to use in addition to Voskresenskiy's map also the map of Spring runoff of L.G.Onufrienko (1962). For the Vorsklitsa and Esman' Rivers the runoff values taken from both maps are close to ours (Table 1). For the Sula River at Zelenkovka our computed runoff agrees better with L.G.Onufrienko's map. The depth of Spring runoff within the entire region ranges from 70 to 50 mm with a noticeable reduction from north to south.

T h e S o s n i n s k i y L i m e s t o n e region has considerably fewer records. An average long-term value of runoff could be derived only for one gaging section, Sosna River at Ivan' 2nd which agreed with Voskresenskiy's map. The strongly developed karst phenomena did not permit to establish a relationship between the flow of the individual rivers of this region. Therefore, only average values of depth of runoff for the period of record at individual points are given in the appendix.

For the Don River Basin there is, in addition to Voskresenskiy's map, also a map of Spring surface runoff prepared by V.N.Parshin and M.S.Salov (1955). The values on this map are lower than those of Voskresenkiy's map.

V.N.Parshin and M.S.Salov consider that the difference could be due to the fact that in computing the Spring runoff for small rivers, Vorkresenskiy lengthened the high-water period and made the conversion to a period during which the flow according to the streamflow data at the Kalach Gaging Section was higher than that for the 1930-1951 period used in constructing their map. However, according to our analysis, the flow of the 1930-1951 period is close to the normal.

T h e T i m s k i y C e n t r a l - W a t e r s h e d D i v i d e Region is also poorly covered by observation. Only on the western boundary of the region are there runoff

data for the Rat' River. The runoff at both gaging stations on this river is 20% smaller than that on Voskresenskiy's map. This can be explained partially by the fact that there is karst in the headwaters of the river.

In the O s k o l o - D o n e t s limestone region there are also karst phenomena. The flow of small rivers in this region can be determined from only two gaging stations: Oskolets River at Oskol and Vezelka River at Belgorod. The average flow at the Oskolets River is 15% lower than on Voskresenskiy's map and for that of the Veselka River it is 30% higher. The reason for the latter discrepancy is difficult to explain without special investigations.

T h e C i s - D o n C h a l k region includes the Nizhnedevitskaya Runoff Station. The records at this station do not show the high runoff values on Voskresenskiy's map. The data agree considerably better with the Parshin-Salov map. The average deviation from the Voskresenskiy map is 34% and from the Parshin-Salov only 3%. The depth of runoff ranges approximately from 50 to 70 mm.

Of the other regions the northeast of the CCP (the Tsna River Basin) is relatively well covered with observations. This part includes the Tsninskiy, the Northeastern Tsninskiy and the Eastern Vorono-Tsninskiy physical-geographical regions. The flow of small rivers in these regions is approximately 15% lower than that shown in Voskresenskiy's map. The Chelnovaya River and its tributary, the Dvoynya River, the flows of which are very high, are an exception. A.A. Sokolov (1962) explains this exception by the possible non-coincidence of the surface and underground catchments of the Dvoynya River. This apparently explains the high flow of the Chelnovaya River. According to our data the average runoff in the Tsna River Basin ranges from 70 to 120 mm.

On the boundary between the Central Flat and the Southern Bityugo-Khoper physical-geographical regions lies the Dokuchaev Agricultural Institute of the CCP, and the Kamennaya Steppe Hydrometeorological Observatory. Runoff measurements were made over a number of years on the areas of these institutions. The average discrepancy with Voskresenskiy's map is 37%. The discrepancy with the Parshin-Salov map is somewhat smaller.

It is necessary to note that for the very small catchments of the forest-steppe and steppe zones (up to 5 km^2) the normal runoff taken from Voskresenskiy's map was reduced by 25% in accordance with his recommendations. Voskresenskiy explains this reduction by the entry of part of the subsurface runoff on small catchments into deeper soil horizons lying below the stream channels or below the bottoms of ponds. Therefore, on small catchments normal runoff can be affected by two opposing processes: on the one hand the normal runoff can be increased by the accumulation of snow in the ravine and, on the other hand, it can be reduced by the subsurface outflow into deeper horizons lying below the gaging stations. All this creates additional difficulty in the evaluation of the average long-term runoff from small catchments. The average depth of runoff on this territory ranges from 30 to 40 mm. It is possible that the average runoff on the area of the Agricultural Institute is even somewhat lower than on the adjoining areas because of improved agricultural practices on its fields which result in higher infiltration. To the north and northeast of the area of the Institute the average depth of runoff increases to 70-80 mm.

The southeast of the CCP is poorly covered with observations on small rivers. The few gaging stations are located quite far apart which makes it difficult to correlate their records. The flow of these stations

(the Osered, Ol'shanka and Kriusha Rivers) is approximately the average between the values taken from Voskresenskiy's and Parshin's-Salov's maps.

Winter Floods

Investigators usually include in the total volume of the Spring high water also the volume of winter floods. Yet winter floods themselves can play an important role in the flow of small streams and therefore in the feeding of ponds and reservoirs. The fact is that appreciable winter floods can fill reservoirs even in the middle of the winter. In such cases even small volumes of Spring high water can wash out the dams or can lead to considerable erosion of the spillways. Concrete examples of such occurrences are reported in S.A.Kremez' (1960) paper. Information on the volume and frequency of winter floods could make possible proper operation of ponds which would lead to lengthening the period of their usefulness.

The principal difficulty in the study of the problem of winter floods consists in that the periods of record for small rivers are short and it is difficult to analyze them statistically for the purpose of determining the frequency of their volumes.

As was indicated above, the period from 1950 to 1959 inclusive can be considered close to the normal for the territory of the CCP. Volumes of surface runoff of winter floods for this period were determined for the watercourses listed in Table 1 by planimetering hydrographs of winter floods on which the ground water flow was separated beforehand. Volumes of runoff of winter floods expressed in millimeters are given in Table 2.

First to be noted is the fact that floods occurred in seven of the ten examined winters and that several floods often occurred in one winter.

RUNOFF OF WINTER FLOODS, mm

TABLE 2

River	point	1950				1951-1952					1952-1953				1954-1955					1956-1957					1958				1958-1959				Average winter flood runoff
		II–III	III	Spring	% of Spring runoff	XII	I	II	Spring	% of Spring runoff	XI	XII	Spring	% of Spring runoff	XII	I	II	Spring	% of Spring runoff	XII	II	III	Spring	% of Spring runoff	II	III	Spring	% of Spring runoff	XII	I–II	Spring	% of Spring runoff	
Oka	at Benderovo	—	—	—	—	—	6	—	70	9	7	7	70	20	—	—	3	84	4	<1	5	2	36	20	—	5	59	8	4	—	59	7	
Kroma	" Cherkasskaya	—	—	—	—	—	<1	—	73	—	3	8	58	19	—	—	<1	78	—	<1	4	<1	43	9	—	—	79	—	1	2	52	6	
Tson	" Novolunie	17	—	22	77	5	<1	—	88	6	<1	14	68	21	—	—	<1	75	—	<1	8	<1	59	14	—	3	89	3	8	—	63	13	6
Rybnitsa	" Lyubonovo	—	—	—	—	—	5	—	80	6	12	12	54	44	—	<1	5	100	5	<1	4	—	43	9	—	1	69	—	5	—	66	8	
Orlitsa	" B. Rog	22	7	30	97	—	<1	—	88	—	3	11	67	21	—	—	—	78	—	—	4	—	43	9	—	—	79	—	4	<1	52	8	5
Metsnya	" Mtsensk	—	—	—	—	—	<1	<1	48	—	2	14	38	42	—	5	1	66	8														
Kur	" Kazatskaya	—	6	42	14	1	9	—	72	14	1	3	90	4	3	7	14	89	27	2	1	6	29	31	—	10	39	26	8	—	52	15	7
Usozha	" Fatezh	17	—	30	57	4	9	—	77	17	6	10	50	32	<1	2	12	71	20	—	15	—	33	45	—	6	65	9	4	4	54	15	9
Svapa	" Loktionovo	—	—	—	—	5	12	—	95	18	8	6	49	28	<1	1	10	95	12	—	9	—	45	20	—	7	78	9	4	—	63	6	8
Prut	" Shirkovo	26	—	24	107	6	14	—	65	31	12	12	55	44	<1	—	13	54	24	—	15	—	27	55	2	8	32	31	6	—	42	14	11
Dublyanka	" Ryl'sk	—	—	—	—	—	16	9	77	32	12	19	138	22	—	89	42	65	200														
Vorsklitsa	" Mokraya Orlovka	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	40	—	37	119	—	3	40	8	1	5	17	35	
Sula	" Zelenkovka	—	—	—	—	—	—	2	80	2	6	24	66	46	—	4	34	44	86	7	68	—	38	197	15	33	26	184	2	11	14	93	21
Esman'	" Rotovka	—	—	—	—	—	2	—	50	4	2	12	74	19	—	3		84	4	—	14		16	88	—	1	—	—	7	—	13	54	6
Artibya	" Berezhki	—	—	—	—	—	—	—	—	—	24	48	88	82	20	Пр*	Пр*																
Rat'	" Ozerki	3	2	28	18	—	—	6	85	7	2	20	102	22	3	8	20	84	37	—	5	—	28	18	—	8	39	20	—	1	25	4	7
Rat'	" Besedino	—	6	23	26	—	—	7	76	9	4	Пр*	—	—	6	5	22	71	46	—	8	—	26	31	—	5	24	21	3	—	35	9	8
Oskolets	" Oskol	—	—	—	—	—	4	<1	60	7	<1	7	76	9	10	28	23	30	200	2	32	—	40	85	4	11	14	100	2	—	25	8	12
Vezelka	" Belgorod	38	—	21	180	—	<1	5	56	9	4	19	74	31	13	54	47	8	1425	7	43	—	48	104	—	24	11	218	6	<1	48	12	26
Veduga	" Akulovo	2	6	26	31	Пр.*	Пр*	—	—	—	—	—	—	—	12	—	—	—	—	—	28	—	89	31	6	5	32	34	3	—	64	5	
Devitsa	" Nizhnedevitsk	4	1	21	24	3	1	2	90	6	—	15	76	20	11	10	16	48	77	2	35		55	67	2	13	20	75	4	—	54	7	12
Yasenok Creek		—	9	16	56	—	—	5	57	9		10	64	16	19	32	31	33	248														
Barauk Creek		—	—	—	—	—	4		26	15	1	15	85	18	13	19	33	54	120														
Rossosh'	" Podgornoe	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Пр.*	32	—	51	63	11	13	12	200					
Osered	" Buturlinovka	<1	1	20	10	<1	1	—	51	2	—	<1	—	—	4	40	94	30	460	1	15	—	58	28	—	17	37	36	1	<1	39	3	18
Kersha	" Pakhotn. Ugol	—	—	—	—	—	—	—	—	—	—	<1	—	—	12	26	19	132	43	—	3	—	62	5	5	—	35	14	3	—	57	5	9
Pilava	" Knyazhevo	—	—	—	—	—	—	—	—	—	—	28	83	34	<1	Пр.*	1	131															
Khava	" Il'inovka	—	—	—	—	—	—	—	—	—	—	10	88	11	14	25	25	59	109	1	48	—	78	62	1	6	49	14	2	<1	64	3	14
Karian	" Sergeevka	—	—	—	—	—	<1	Пр*	—	—	—	Пр*	—	—	10	5	16	125	25	—	11	—	119	9	—	—	—	—	3	—	43	7	
Chelnovaya	" Pudovkino	—	—	—	—	—	—	—	—	—	—	—	—	—	9	35	32	200	38	—	5	—	119	4	—	1	44	2	5	—	78	6	
Dvoynya	" Ostroukhovo	—	—	—	—	—	—	—	—	—	—	—	—	—	22	20	30	195	37	<1	6	—	155	4	—	17	65	26	4	—	92	4	13
Karachan	" Aletki	—	—	—	—	—	<1	—	—	—	—	—	—	—	—	—	Пр.	87	—	1	9	—	105	10	4	11	73	21					
Ozernyy	" V. Orlonka	—	—	—	—	—	Пр*	Пр*	—	—	—	<1	—	—	<1	18	40	54	108	<1	10	—	44	23	—	13	22	59	1	—	37	3	
Kleshnya	" Rakitino	—	—	—	—	2	3	—	59	8	—	11	97	11	Пр*	9	21	107	28	3	20	—	136	17	3	15	40	45	6	—	52	12	13
Repnyy Chenka	" Krasnore-	—	—	—	—	—	—	—	—	—	—	Пр*	—	—	1	Пр*	Пр*	117	—	Пр*	41	—	205	20	27	44	148	48	6	—	54	11	
Lomovis	" Rozhde-stvenskoe	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	3	182	5	—	1	—	107	0	—	—	—	—	9	—	93	10	
Unnamed cr. Chatanovka	"	—	—	—	—	—	—	—	—	—	—	—	—	—	3	6	3	259	5	1	3	—	319	1									
Ol'shanka	" Krepov-skiy	1	—	—	—	—	—	—	—	—	—	—	—	—	—	25	63	12	733	—	16	—	63	25	6	14	23	87	—	—	—	—	13
Kriusha	" Kriusha	—	—	—	—	—	—	—	—	—	—	—	—	—	<1	Пр*	—	—	—	Пр.*	Пр*	—	—	—	19	10	13	223					
Peskovatka	" Shumilinskaya	—	—	—	—	—	—	—	—	—	—	<1	—	—	—	31	54	2	4250	—	17	—	47	36	32	14	7	657	—	—	—	—	15

*Negligible

Floods occur in all winter months from January to March. Important floods (1955, 1957, 1958) as a rule cover the entire territory of the CCP. It is true that in 1950 and 1951 there were no floods in the northeast of the CCP (Tambov Province) and in 1952 there were none also in the southeast of the CCP.

Floods occur when warm air masses from a cyclone centering above the Baltic Sea enter the southwest and the Central European territory of the Soviet Union and when cyclones enter from the Mediterranean (Zaykov,1946) at the time when anticyclonic activity develops over western Siberia.

Important floods occur when, in a given month, western and eastern types of atmospheric circulation of G.Ya.Vangengeym's classification develop and frequently follow each other. The development of a western circulation produces copious precipitation and high temperatures. The eastern type of circulation is conducive to the development of the Siberian anticyclone and to its shifting to the west and covering of part of the European territory of the Union. With a strongly developed anticyclone on part of the European territory of the USSR cyclonic systems move over its western part and copious precipitation occurs.

The winter floods of 1950 developed at the end of February - beginning of March on most of the territory of the CCP excepting its northeastern part (Tambov Province). It was strongly developed in the Orel and Kursk Provinces where it amounted to almost 100% of the volume of the Spring high water.

Flood runoff is determined primarily by the amount of water reaching the surface of the basin. The supply on the surface of the catchment can be determined from snow survey data. Comparing the depth of flood runoff with the supply of water on the surface of the basin gives an idea of the magnitude of the runoff coefficient. Air

temperature and the snow density must be considered in the analysis. Such an analysis for the 1950 flood was made for three gaging stations (Usozha River at Fatezh, Kur River at Kazatskaya, and Vezelka River at Belgorod) which lie in different latitudes (Fig. 2). Information on the runoff coefficient is given in Table 3. It is notable that the runoff coefficient for the Veselka River at Belgorod is considerably higher than for the two other gaging stations located further north.

This is due principally to the sum of positive temperatures. For the thaw period this sum was plus 4^{o} in the Kursk and Fetezh Regions and considerably higher in the Belgorod Region. In the Fatezh and Kursk Region a considerable amount of snow (up to 10-12 cm) still remained after the thaw,while in the Belgorod Region the snow was completely removed. In the northern parts of the CCP thaws caused a compaction of the snow and partial melting, and with subsequent cooling the formation of an ice crust. Thawing occurred in daytime hours and freezing at night. Higher temperatures in the south caused higher rates of melting which produced higher runoff coefficients. This picture is apparently characteristic for winter floods in the CCP. For the Vezelka River at Belgorod the runoff coefficients are generally almost always considerably higher than in more northerly regions.

In general, it follows from Table 3 that the runoff coefficients of winter floods in the northern and middle parts of the CCP are not particularly high. The considerable losses of winter flood runoff may be different in nature. With a thaw with a large sum of positive temperatures preceded by a shallow snow cover and low soil moisture, large infiltration losses can be expected.

In the 1954/55 winter several thaws were followed by freezes which led to the forming of a thick ice crust.

TABLE 3

RUNOFF COEFFICIENT FOR WINTER FLOODS

River, point	1950		1951	1952					1953		1954	1955			1957	1958		1959	1960
	II–III	XI–XII	XII	I	I	II	XI–XII	XII	I	XII	XII	I	II	II	II–III	III	XII	I	I–XII
Usozha at Fatezh	0.31	—	—	0.12	0.32	—	0.20	0.72	—	—	—	0.05	0.23	0.20	0.22	0.11	—	0.07	0.20
Kur at Kazatskaya.	0.13	—	—	0.17	пр.*	—	—	0.30	—	—	0.11	0.27	0.26	0.19	0.09	0.23	0.30	—	0.35
Vezelka at Belgorod.	0.77	0.22		—	—	0.17	0.11	0.59	0.39	—	0.75	0.68	0.99	0.93	—	—	—	—	—
Kleshnya at Rakitno.	—	—	0.11	0.12	—	—	—	0.28	—	0.15	пр.*	0.16	—	0.27	—	—	—	—	—

* Negligible

In such cases the reduction in the supply of water on the catchment cannot be equated to losses (Parshin and Morokhovets, 1958). Melt water is not absorbed by the soil but is accumulated in small depressions of the relief and in front of snow barriers and subsequently freezes.

It is interesting to note that in the northern and middle parts of the CCP the runoff coefficient was not high even in the presence of an ice crust. This is apparently explained by the small sum of positive temperatures. In the south of the CCP (Vezelka River at Belgorod) the combination of an ice crust with a high temperature during the thaws (up to 10-15° above 0) led to exceptionally high runoff coefficients.

Winter thaws in the examined 10-year period were followed by precipitation in the form of wet snow and often in the form of rain. As seen in Table 2 volumes of winter floods are, on the average, not very large but in individual years their volumes can exceed that of the Spring high water, as for instance, in 1955. The average winter runoff for the 1950-1959 period increases from 5 mm in the north of the CCP to 15 mm in the south. For individual gaging stations this value is even greater (Vezelka River at Belgorod - 26 mm, Osered River at Buturlinovka - 18 mm). These average values for the last decade are to a large extent determined by the year 1955 with its many thaws. There are not enough data on small streams for the computation of the frequency of different volumes of winter floods. In the solution of this problem it is apparently necessary to establish correlations with medium rivers having longer periods of record. Such work is being planned for the future.

Precipitation on the Surface of the Reservoir

The determination of the amount of precipitation falling on the surface of reservoirs involves two problems:

1) determination of the amount of atmospheric precipitation for the period when the reservoir is free of ice; 2) determination of precipitation for the period when the reservoir is covered with ice.

For the open-water period the amount of precipitation is determined from data of nearby rain gage stations. In the case of a general rain covering a large area the error in the determination of precipitation on the water surface from rain gage stations is not great. In case of intense rain which could be local in character cases can be encountered when the precipitation at a station located at some distance from the reservoirs can differ considerably from the amount of precipitation over the water surface of the reservoir. Therefore, for such a period it is necessary to have a rain gage at the water line of the reservoir. For the largest reservoirs in the CCP (of the order to 30 ha and more), it is desirable, keeping in mind their shape, to have rain gages at the upper part and at the dam. Such an arrangement was used by the expedition of the Laboratory of Limnology of the Acad. of Sci. USSR on the Uspenskoe Reservoir (Sorokin,1963). The desirability of having several rain gages is clearly seen there.

During the summer-fall period the proportion of precipitation in the water balance of reservoirs can be extremely variable, up to 100% of the incoming part. We obtained such a value, for instance, for the small wooded Berezovoe Reservoir in the falls of 1956 and 1957 when, in running off, the precipitation on the catchment was completely absorbed and did not reach the reservoir. Precipitation on the water surface at that time was the only incoming part. On the larger Uspenskoe Reservoir the part of precipitation falling on the water surface during the summer reaches 50% and more. On the Borshchenskoe Reservoir this part reduces to 10-15%.

It is of interest to determine evaporation expressed as a proportion of the water volume during the summer period. For this purpose we utilized the results of the reservoir surveys which we made in 1957-1959 (Sorokin and Yakovleva, 1961). The calculation was approximate. We assumed the normal volume of the reservoir to be that at the time of the survey (middle of the summer).

The normal evaporation for the summer-fall period (May-October) for the investigated region was taken from L.F.Forsh's calculation (Table 4).

The first thing to be noted in the table is a general increase in evaporation from north to south. For the north of CCP (Orel Province) the evaporation losses average about 20% of the normal volume of the pond. In the south of the Kursk Province these losses increased to 40% and in the Voronezh Province (Kamennaya Steppe District) to 50% and more. In addition to the zonal increase in evaporation from north to south the value of evaporation is influenced somewhat by the shape of the ravines which can be represented by the stage volume curve $V=f(H)$.

Three $V=f(H)$ curves for the three above-indicated parts of the CCP are shown in Fig. 3. Since evaporation takes place in the upper meter layer, it is proper to compare the upper portions of the shown curves. It can be seen that in the first meter below the surface Curve I is steeper than Curves II and III, i.e., the depths increased faster, the shallow zone is smaller, the slopes of the ravine are steeper and evaporation losses are smaller. Type I curves are typical for the dissected relief of the center of the Mid-Russian Highland.

Curves II and III are similar. The parts of the curves for the first meter layer are flatter, the ravines are wider, the shallow zone is larger and the evaporation is greater. These curves are typical of the considerably

TABLE 4

EVAPORATION LOSSES FROM THE WATER SURFACE OF PONDS

Location of pond, district	Normal volume V, $10^3 m^3$	Evaporation h for May-October, mm after Forsh.	Water volume minus evaporation V', $10^3 m^3$	Evaporation losses: V—V', $10^3 m^3$	Evaporation losses: %	Normal 1950-59 May-Oct. precip., mm	Effective evaporation (h-x), mm	V''-water volume minus losses (h-x) $10^3 m^3$	Evaporation losses: V—V'', $10^3 m^3$	Evaporation losses: %
Kursk Province										
Durovka, Korenevskiy Dist.	140.1	610	100.0	40.1	29	369	241	125.0	15.1	11
Kremyanoe (field), Korenevskiy Dist.	211.4	615	159.0	52.4	24	369	246	190.0	21.4	10
Kremyanoe (village), Korenevskiy Dist.	268.4	615	181.0	87.4	32	369	246	230.0	38.4	14
Blagodatnoe, Korenevskiy Dist.	51.2	610	34.0	17.2	33	369	241	44.0	7.2	14
Sheptukhovka, Korenevskiy Dist.	85.0	615	58.0	27.0	33	369	246	74.0	11.0	13
Murinovka, Korenevskiy Dist.	88.8	615	60.0	28.8	32	369	246	76.0	12.8	14
Viktorovka, Korenevskiy Dist.	99.7	620	75.0	24.7	25	369	251	89.5	10.2	10
Rshava, B. Soldatskiy Dist.	226.0	615	138.0	88.0	39	352	263	188.0	38.0	14
Storozhevoe, B. Soldatskiy District	580.6	615	450.0	130.6	23	352	263	525.0	55.6	10
Nemcha, B. Soldatskiy Dist.	80.0	620	50.0	30.0	37	352	268	66.0	14.0	17.5
Levshinka, B. Soldatskiy District	74.5	620	43.0	31.5	41	352	268	60.0	14.5	19
Skorodnoe, B. Soldatskiy District	127.8	620	67.0	60.8	47	352	268	99.0	28.8	22
Zaoleshnya, B. Soldatskiy District	66.1	620	40.5	25.6	39	369	251	57.0	9.1	14
Lebedin, Lenin District	17.7	615	5.5	12.2	69	357	258	11.5	6.2	31
Mal'tsevo, Lenin Dist.	235.4	615	176.0	59.4	25	357	258	210.0	25.4	11
Artyukhovka, Lenin Dist.	9.17	615	3.2	6.0	67	357	258	6.3	2.9	31
Kukuevka, Streletskiy Dist.	18.1	615	8.0	10.1	56	380	235	13.6	4.5	25
Tsvetovo I, Streletskiy Dist.	73.5	615	380.0	35.5	48	380	235	57.5	16.0	22
Kondratovka, Belovskiy Dist.	41.9	645	15.2	26.7	63	369	276	30.0	11.9	28
Kamyshnoe, Belovskiy Dist.	137.0	645	54.0	83.0	61	369	276	100	37.0	27
Boshkatovo, Oboyanskiy Dist.	159.1	625	87.0	72.1	45	369	256	128	31.1	20
Durnovka, Ivaninskiy Dist.	33.6	610	10.4	23.2	69	335	275	21.3	12.3	37
				Average	42				Average	19
Orel Province										
Kromy	189.0	540	155.0	34.0	18	373	167	176	13	7
Malaya Kulikovka	160.0	540	117.0	43.0	27	373	167	145	15	9.5
Al'shanskie vyselki	72.0	530	57.0	15.0	21	373	157	65	7	10
Pervyy voin	194.0	540	145.0	49.0	25	373	167	178	16	8
				Average	23				Average	10
Voronezh Province										
Osinovskiy (Nizhniy), Talovskiy District	36.6	725	18.6	18.0	49	241	484	24.0	12.6	34
Osinovskiy (Sredniy), Talovskiy District	65.2	725	33.0	32.2	49	241	484	43.0	22.2	34
Osinovskiy (Verkhniy), Talovskiy District	11.9	725	4.4	7.5	62	241	484	6.5	5.4	45
Mikhinskiy, Talovskiy Dist.	44.3	725	17.5	26.8	61	241	484	23.5	20.8	46
Starodubovskiy (Nizhniy), Talovskiy Dist.	300.0	725	237.0	63.0	21	241	484	260.0	40.0	13
Starodubovskiy (Verkhniy), Talovskiy Dist.	48.6	725	30.0	18.6	38	241	484	37.0	11.6	24
				Average	47				Average	33

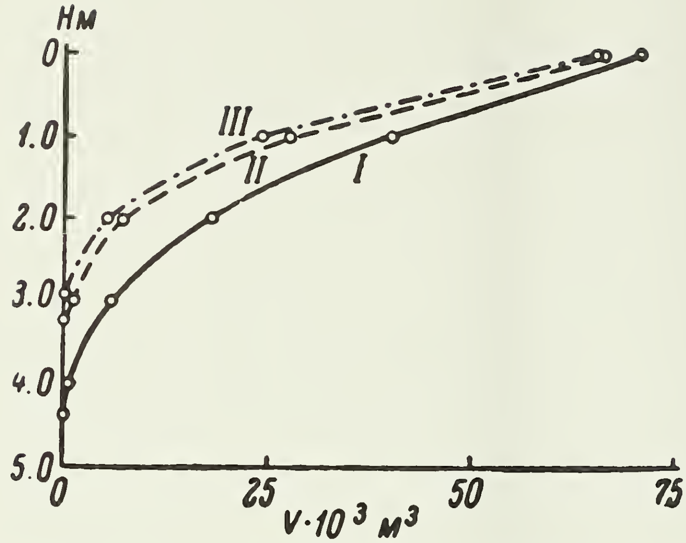

FIG. 3. Stage-Volume Curves of Reservoirs

I - Pond at the Village Al'shanskie Vyselki (Orel Province);
II - Pond at Village Zaoleshnya (southern Kursk Province);
III - Pond on the Osinovaya Ravine (Voronezh Province).

smoothened out territory - the southwestern slope of the Mid-Russian Highland and the Oksko-Don Depression. For individual regions with similar physical-geographical conditions the evaporation losses are greatest for shallow ponds located in the headwaters of ravines. For instance, in the Voronezh Province: 62% for Osinovskiy, Verkhniy, and 61% for the Mikhinskiy Ponds. On ponds located in the lower reaches of ravines where the entrenchment is greater and the slopes are steeper the evaporation losses reduce to 20% (Starodubovskiy Nizhniy)(Table 4).

Large evaporation losses are to a considerable extent compensated by precipitation. In Table 4 is computed the so-called "apparent" evaporation, i.e., the difference between evaporation and total precipitation. We computed the average precipitation for the 1950-1959 decade from the data of the meteorological stations located in the immediate vicinity of the investigated reservoirs. Taking into account the precipitation the evaporation

losses are reduced to 10% in the north of the CCP to 20% in the south of the Kursk Province and to 30% in the Kamennaya Steppe region.

Seepage from Reservoirs

Seepage from reservoirs is one of the most important elements of the debit side of the water balance of reservoirs. As is known, seepage losses can be subdivided into temporary and continuous. Temporary losses occur in the first year of existence of ponds when the contact between the water in the reservoir and the ground water takes place. This period can be different for different reservoirs depending on the depth to ground water and on the formation composing the sides and the bottom of the ravine. Thus temporary seepage losses occur in almost all the reservoirs over the entire CCP territory. Continuous seepage losses, however, are connected with the difficult hydrological conditions of ravines consisting of the outcropping at the surface of permeable formations or of their presence close to the surface and of the great depth to ground water both in the bottom of the ravine and in its side. Continuous seepage losses are to a large degree connected with the outcropping of chalk-marl deposits and of limestone. Such cases are observed in the southeastern districts of the Kursk Province, in the Belgorod Province and on a considerable area of the Orel Province (the inter-river areas of the Oka, Zusha, Sosna and Krasivaya Sosna Rivers).

But considerable losses can occur also where there are no outcrops of fractured chalk-marl deposits. "Many ponds constructed on clay loam soils underlain with sand and fractured rocks retain the water very poorly even when the clay loam layer is thick. The rate of outflow of water from such ponds reached tens of centimeters per day" (Kazarnovskiy, 1959).

In Kazanovskiy's opinion substantial seepage can occur even in ponds that are lined with loams because of the vertical micro-porosity and the aggregation of loess-like clay loams.

Early experience in the construction and operation of ponds and reservoirs confirmed the expected losses and, in many cases, the losses proved to be considerably higher than expected.

As is known, seepage losses on many ponds are reduced in the course of time. This is the result not only of the contact between the water in the reservoir and the ground water but also of natural sealing resulting from the silting of reservoirs.

In 1952 the Giprovodkhoz of CCP made a survey of leaky reservoirs and determined the reduction in seepage during the first years of existence of the reservoir. Excerpts of these data are given in Table 5 and the location of the inspected ponds is shown in Fig. 4.

Table 5 shows that reduction in seepage losses varies strongly for different ponds even within a relatively small area. This variation is due to the specific conditions of the reservoirs. In some reservoirs the seepage is reduced more than half in the second year. In others, the reduction is considerably less. In still others, there is no reduction at all (see Table 6). The latter are those with dry fractured marl and silty clay loam close to or at the surface. In individual cases karst dolinas are present.

Table 6 shows that in individual cases seepage may even increase with time. Such a case is reported by G.S.Pashnev (1960). He found dolinas 0.5 to 30 m in diameter and 2-3 and more m. deep in drained ponds in the Orel and Lipetsk Provinces where karst is encountered in the limestone. He explains this by the forming of sinks resulting from the seepage of water from the pond.

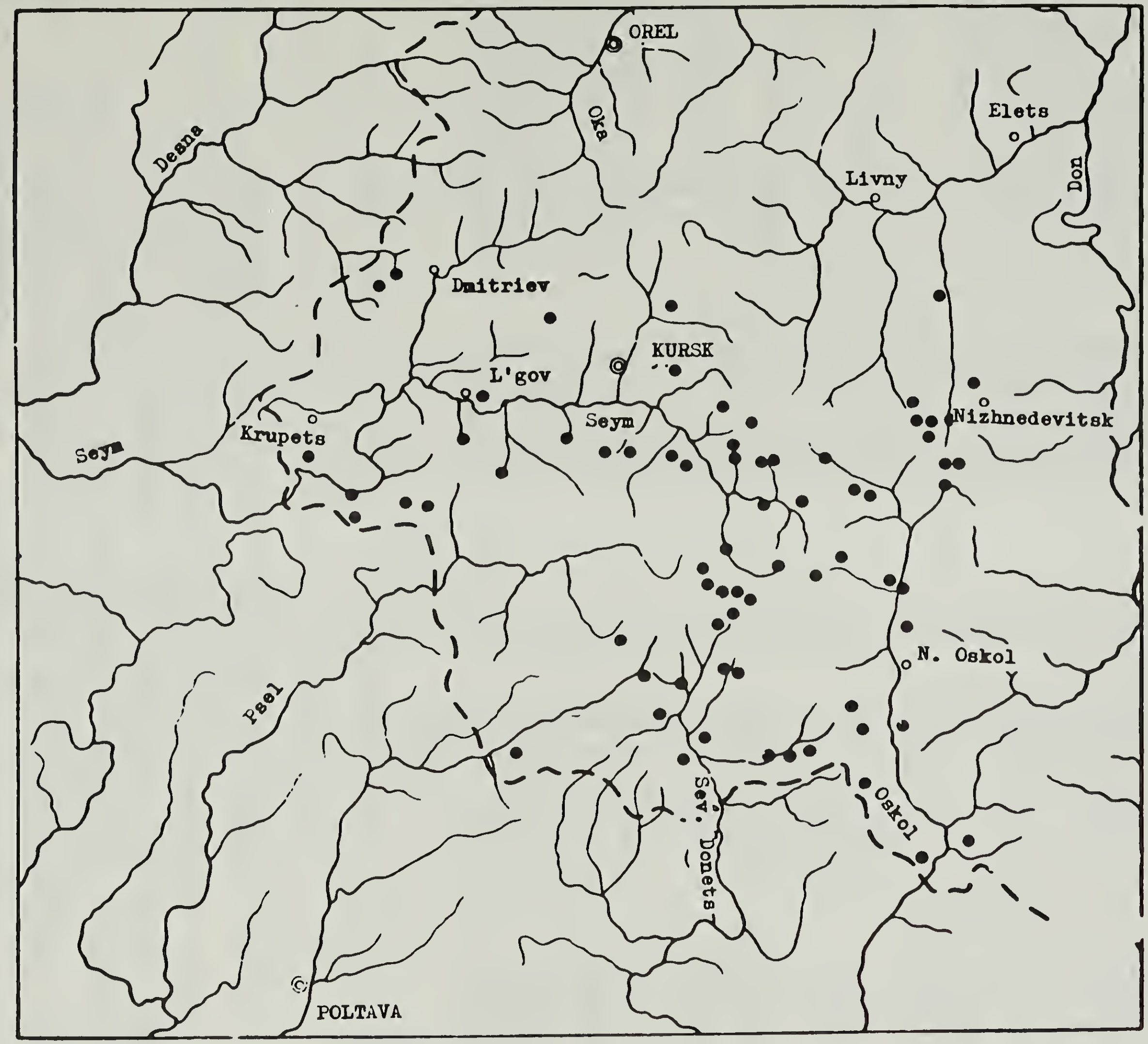

FIG. 4 LOCATIONS OF PONDS WITH SMALL INITIAL CAPACITY (BASED ON DATA OF THE CENTRAL CHERNOZEM PROVINCE GIPROVODKHOZ)

Dots show investigated ponds.

TABLE 5

REDUCTION OF SEEPAGE IN THE PONDS OF THE KURSK AND BELGOROD PROVINCES

District	Surface area, ha	Seepage coefficient cm/day		
		1950	1951	1952
Volokonovskiy . .	19.0	—	18.0	16.6
Chernyanskiy . .	3.82	—	30.0	27.4
Staro-Oskol'skiy	19.5	—	20.0	5.2
	12.5	—	36.0	17.3
Manturovskiy. . .	—	3.2	1.0	—
Yastrebovskiy . .	45.0	—	15.6	6.1
Manturovskiy . .	5.0	—	8.4	3.3
	—	—	9.0	6.8
Gorshechenskiy. .	7.5	—	9.8	6.6
	4.2	—	25.0	16.0
Prokhorovskiy . .	8.2	—	9.8	8.6
Solntsevskiy . .	7.2	—	15.7	15.0
	9.0	—	12.0	7.5
	8.6	—	14.0	11.7
Shebekinskiy . .	18.0	—	10.0	4.9
B. Troitskiy . .	4.5	25.0	25.0	19.6
Medvenskiy . . .	10.0	20.0	2.0	5.15
Leninskiy	5.0	23.0	11.8	6.7
Sudzhanskiy . . .	15.5	—	5.0	2.0

In 1958 we inspected one of the ponds surveyed in 1952 (in Vill. Lyubimovka of the Korenevskiy District). In 1952 the rate of seepage was 9 cm/day; by 1958 it was reduced to 2 cm/day. But even this value was quite high. This seepage was due to the presence of chalk in the formation comprising the ravine. In addition the considerable forest cover of the catchment area reduced the silt runoff and the process of natural sealing was weakened.

TABLE 6

CHANGES IN SEEPAGE IN PONDS OF THE KURSK AND BELGOROD PROVINCES

District	Surface area, ha	Seepage coefficient, cm/day		
		1950	1951	1952
Valuyskiy	19.0	11.0	16.0	25.0
Volokonovskiy . .	11.0	—	20.0	23.0
Veliko-Mikhay-lovskiy	7.2	—	13.0	15.0
Verkhne-Mkhay-lovskiy	5.5	—	10.0	10.0
	25.0	—	4.8	5.0
Gorshechenskiy .	4.6	—	25.0	26.0
	—	—	5.0	5.0
Belenikhinskiy. .	7.0	—	11.0	13.6
Belgorodskiy . .	7.2	—	12.0	13.0
	6.2	—	6.0	7.0
Glushkovskiy . .	3.55	—	6.8	6.5
Krupetskiy . . .	8.1	—	6.1	8.4
Timskiy	32.2	—	2.0	2.5
Zolotukhinskiy .	3.8	—	6.0	6.0
Grayvoronskiy . .	7.9	—	5.0	5.0

Detailed investigations of natural sealing in the Voronezh Province were made by V.E.Vedenyanin (1961). We showed the reduction in seepage with time on the Borshchenskoe Reservoir (Sorokin, 1961).

In addition to changing from year to year, seepage is subject to variation during the year which can be of great importance in preparing water balances for individual seasons.

It is commonly agreed that with a rise in the water level of the reservoir seepage increases and vice versa. This is confirmed by many observations (Malinina, 1960; Kurdov, 1955; Kalpacheva, 1955; and others). All these investigators as well as the author (1961, 1963) determined

the seepage during the summer when its part in the debit of the balance is especially great and when its determination is of great importance because it is during this period that the pond is utilized - water is diverted for irrigation. In the majority of cases the value determined in the summer is applied to the entire year. Actually, the change of seepage within the year is considerably more complicated.

The investigation in the CCP of the Chair of Hydrogeology of the Moscow Institute of Geologic Explorations during 1949-1954 (Gavich, 1959) established that reservoirs filled by floods have an unstable seepage regime during their operation. In the Spring when the water enters the reservoir its level begins to rise appreciably and seepage into banks of the reservoir increases, thus creating a so-called "underground reservoir." As a result the water level drops and if the water level is used in determining the inflow into the reservoir then the part of the water that seeps into the banks will, in such cases, not be taken into account. Subsequent reductions in the water level of the reservoir result in a change in the seepage regime; which will be "reflected in the appearance of an inflection point on the depletion curves which signifies the beginning of ground water feeding of the reservoir" (Gavich, 1959).

The existence of "an underground reservoir" was disclosed also in the investigations of the water balance of the Rybinskoe Reservoir (Braslavskiy, Byurig, Vikulina, 1951). We disclose the above-described phenomena in preparing the balances for the Borshchenskoe and Uspenskoe Reservoirs in the Kursk Province.

Excerpts from the records of water balances of these reservoirs are shown in Tables 7 and 8. The selected periods are characterized by a sharp drop in the water level

TABLE 7

WATER BALANCE OF THE USPENSKOE RESERVOIR FOR SUMMER PERIODS

Date	Water level, assumed elev.	Diff. in levels, cm	Surface area, $10^3 m^2$	Average surface area, $10^3 m^2$	Water volume change, $10^3 m^3$	Water volume by V=f(H), $10^3 m^3$	Water volume change by V=f(H), $10^3 m^3$	Diversion for irrigation		Precip. on the surface		Surface evaporation		Seepage		Inflow	
								мм	$10^3 м^3$	мм	$10^3 м^3$	мм	$10^3 м^3$	мм	$10^3 м^3$	мм	$10^3 м^3$
1959 August																	
10	95.15	0.624	0.606	2.285	—165.0	278.2	168.6	0.0	0.0	0.0	0.0	39.9	24.4	25.0	15.15	+ 71.3	+ 43.2
20	94.89	0.587	0.577	2.120	— 70.0	86.7	50.0	0.0	0.0	13.2	7.6	54.3	31.3	27.5	15.9	+ 34.0	+ 19.6
31	94.77	0.567		2.050													
1960 May																	
1	96.86	0.869	0.850	3.580	—315.0	583.3	495.8	0.0	0.0	19.2	16.3	22.8	19.4	25.0	21.2	+241.2	+205.1
10	96.48	0.830	0.790	3.265	—465.0	560.5	422.8	13.4	10.6	1.5	1.2	38.7	30.6	25.0	19.6	+ 47.4	+ 37.4
20	95.88	0.749	0.734	2.800	—123.0	106.3	77.0	17.2	12.6	7.3	5.4	62.7	46.0	27.5	20.2	+ 38.7	+ 27.4
June																	
1	95.72	0.720		2.677													

TABLE 8

WATER BALANCE OF THE BORSHCHENSKOE RESERVOIR FOR SUMMER-FALL PERIODS

Date	Water level, assumed elev.	Surface area, $10^6 m^2$	Average surface area, $10^6 m^2$	Water volume, $10^6 m^2$	Changes in water volume, $10^3 m^3$	Siphon discharge		Reservoir wastage, $10^3 m^3$			Berezovoy Reservoir flow, $10^3 m^3$	Surface precipitation		Surface evaporation		Seepage		Inflow, $10^3 m^3$	Inflow, mm
						mm	$10^3 m^3$	Spillway	Siphon	Total		мм	$10^3 м^3$	мм	$10^3 м^3$	мм	$10^3 м^3$		
1956																			
21 Aug.	94.50	—108	371	316	—341.3	834	—352.0	57.5	318.3	375.8	1.1	4.6	1.5	37.3	11.8	11	3.5	+36.5	116
31 Aug.	93.42		267			482													
1957																			
21 Oct.	94.20	-- 80	346	306	—244.8	720	—244.0	—	298.0	298.0	0.5	2.0	0.6	7.0	2.1	11	3.4	+58.6	191
1 Nov.	93.40	- 80	265	234	—150.0	476	—154.0		216.4	216.4	—	—	—	—	—	10	2.1	+64.5	275
11 Nov.	92.76		204			322													

caused by the operation of the siphon and by complete or almost complete lack of precipitation which gives reasons to suppose that there was no inflow from the catchment. Therefore, the values shown in the column "inflow" are the inflow of water from the sides of the reservoir (ground feeding).

Thus, during part of the year the water of the reservoir seeps into the banks; and at other times when the level drops considerably there is underground inflow of water back into the reservoir. For the majority of reservoirs which were in existence for several years there will be no seepage through the silted bottom. There remains, however, seepage around the dam and under it. Its value appears in Tables 7 and 8, in the "Seepage" column. The existence of this seepage is confirmed by observations on water levels in bore-holes drilled by the expedition in the toe of the dam. Water stood in these bore-holes all the time even during the driest summer periods which indicates their continuous feeding.

Conclusions

1. Based on the analysis of residual-mass curves of annual runoff coefficients constructed for individual gaging sections with long periods of record in the greater part of the CCP, the decade 1950-1959 can be considered representative with respect to average flow. This period is better covered by observations on small rivers and intermittent watercourses than are earlier periods.

2. In determining normal runoff the analogue method can be applied only to individual regions with similar physical-geographical conditions. It is advisable to use the regions of the physical-geographical zoning of the CCP carried out by the Voronezh University. In areal interpolation of runoff from reference points one should

not go beyond the boundaries of the physical-geographical regions.

3. A comparison of the mean Spring surface runoff of small rivers and intermittent watercourses computed by the author, with that shown on the maps of Voskresenskiy and of Parshin-Salov shows that in individual cases these values are in close agreement. In some cases, discrepancies are found.

In the northwest of the CCP (Orel Province) the flow of small rivers is everywhere lower than that given by Voskresenskiy's map. In other parts of the CCP cases can be found where the flow of small rivers exceeds map values. Basically, however, the number of cases with values of local runoff lower than that taken from Voskresenskiy's map clearly predominate. In individual cases, there is almost complete agreement with the Parshin-Salov map (Cis-Don Chalk Region). In other cases, there are considerable differences (southern Bityugo-Khoperskiy Region).

4. Winter floods occurred in seven of the ten winters of 1950 to 1959. The floods occur when warm air masses from the cyclone centering over the Baltic Sea enter the southwest and center of the European Territory of the USSR and when cyclones enter from the Mediterranean at the time when anticyclonic activity is developed on the territory of western Siberia.

Winter flood runoff constitutes, on the average, from 5 to 20 mm; in individual years it can exceed the value of Spring high water (1955). Winter floods fill the reservoirs and cause dam failures in the Spring. This makes it imperative to separate them from the total volume of Spring high water and to analyze them separately.

The part of precipitation falling on the water surface in the credit side of the water balance can vary strongly

during the summer-fall period ranging from 10 to 50% and more. During the winter period solid precipitation falling on the ice cover has little effect on the water level because it is moved to the banks where during the drop in the level the ice lies on the ground and does not displace the water. During the Spring period the part of precipitation in the incoming part of the balance reduces to 5%.

6. In the northern part of the CCP evaporation losses constitute about 20% of the normal volume of ponds. In the south of the Kursk Province these losses increase to 40% and in the Voronezh Province - to 50% and more. Large evaporation losses are, to a considerable extent, compensated by precipitation. "Apparent" evaporation losses are reduced to 10% in the north of the CCP to 20% in the south of the Kursk Province and to 30% in the Kamennaya Steppe (District). Under normal hydrogeological conditions natural sealing which leads to a reduction in seepage losses occurs in reservoirs of the CCP. Seepage changes also during the year in connection with the fluctuations in the water level of the reservoir; in individual instances, seepage can change its sign, i.e., there can be inflow into the reservoir from the banks (ground-water seepage).

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L. F. F O R S H

MAP OF EVAPORATION FROM SMALL RESERVOIRS OF THE CENTRAL CHERNOZEM PROVINCES

In planning and operating reservoirs it is necessary to consider the possible evaporation losses because they constitute the principal part of the outgoing part of the water balance of reservoirs.

The existing maps of distribution of evaporation both for the European part (Davydov, 1944; Zaykov, 1949) as well as for the entire country (Braslavskiy and Vikulina, 1954) considerably facilitate the tasks of the planners.

But these maps which are prepared for large areas are, to a certain extent, general.

In 1949 a map of evaporation from the surface of reservoirs of the Central Chernozem Provinces (CCP) was published (Voskresenskiy, 1949) which was based on the map of V.K.Davydov.

Coefficients were applied to the values of evaporation given on this map to convert them from normal to evaporation of 3 and 20% frequencies and corresponding maps were prepared for the entire frostless period as well as for the summer months (May-August).

Inasmuch as Voskresenskiy's map was based on Davydov's generalized map it cannot claim greater detail.

In addition, the values of evaporation in Davydov's map were computed from meteorological data averaged over the period from 1880 to 1935 for which very little data was available for the territory of the CCP on wind velocity, so that to obtain evaporation for only 15 points in the considered provinces, the author had to resort to the analogue methods.

In post-war years the net of meteorological stations in the CCP was considerably expanded and, what is very important, the quality of meteorological data was improved

by standardization of observation, as well as by increased attention to the weather service.

During these years the number of evaporation stations equipped principally with surface evaporimeters (GGI-3000) was increased. The number of evaporation tanks was also increased.

It is true that in the CCP evaporation stations with relatively long periods of record (not less than 8-10 years) exist only at Kursk (now at Ushakovo) and at Nizhnedevitsk where an evaporation tank with an area of 20 m^2 has been functioning since 1954. Nevertheless, the data of evaporation stations of neighboring provinces can be useful in the construction of an evaporation map of the considered territory.

The investigations of the Laboratory of Limnology on the reservoirs of the Kursk Province during the summer months 1956-1960 ("Transactions of the Laboratory of Limnology", Vol. XIII, 1961; Collection "Hydrologic Problems of the Uspenskoe Reservoir and of its Catchment", L., 1963) made it possible to gather data for the preparation of a map of evaporation from reservoirs of the CCP that is more detailed and is based on a considerably larger quantity of data than the previous maps. Inasmuch as the new maps are based on relationships observed on reservoirs of the considered territory it can be assumed that they should reflect the natural characteristic of the CCP.

In the preparation of an evaporation map it is necessary to consider the type of reservoirs for which it could be applicable, since the morphological characteristics, the depth of entrenchment of the reservoirs, its exposure with respect to prevailing winds and so forth, exert an influence on the rate of evaporation from its water surface.

Because the investigations of the laboratory were conducted on small reservoirs (30-60 ha in area with an average depth of 2-3 m) located in quite deeply entrenched

gullies the prepared map must apply to this type of reservoir.

For the years of the work of the expedition on the two reservoirs of the Kursk Province sufficiently dependable relationships were obtained for the basic meteorological element between the reference meteorological station of the Kursk Zonal Irrigation Reclamation Station (KZIRS) and the meteorological stations which operated on these reservoirs.

Because the considered reservoirs are typical of the CCP with respect to size and morphological characteristics the relationships obtained for them can be extended to the entire area of these provinces provided that some correction coefficients are applied to map values when applying them to large reservoirs. As is known, there is as yet no absolute criterion for determining the validity of the obtained value of evaporation. Some investigators believe that the highest accuracy is obtained by the method in which the value of evaporation is determined as the residual member of the water balance equation.

But we cannot, except in rare cases, obtain even the main members of the equation from direct observation, some of them (ground-water feeding, seepage) are obtained by computation which, in turn, makes the value of evaporation computed by this method doubtful.

The evaporation from the water surface of a land evaporation tank can be taken as some criterion of the correctness of the obtained value of evaporation from a reservoir. But even in this case one can only judge the order of magnitude because the application of the readings of an evaporation tank to a natural reservoir leads to new error.

The computation of evaporation by the heat balance method gives fair results if all the members of the equation are determined with a sufficient degree of

dependability. In such a case, the computed evaporation can be considered close to the actual.

The method of computing evaporation from data on the heat and moisture flux above the reservoir (method of turbulent diffusion) is now being widely used. As shown by observation, this method when used in the computation of evaporation from reservoirs of the ravine type gives overestimated value but can apparently be used successfully for large lakes like Sevan, Balkhash and others (Ogneva, 1958).

For the reservoirs of the Kursk Province the value of evaporation was obtained both by computation and by floating and land evaporimeters (GGI-3000). A reduction coefficient of 0.80 was applied to the readings of the floating evaporimeters (Forsh, 1961).

By comparing the results obtained with different methods (Forsh, 1963) we concluded that under conditions of the Kursk Province, evaporation can be computed with sufficient dependability by the hydrometeorological method using the following formula:

$$E_{mo.} = 0.12n \cdot D(1+0.72W), \qquad (1)$$

where $E_{mo.}$ - monthly evaporation in mm; D - average monthly vapor pressure deficit at 200 cm above the water surface, mb; W - average monthly wind velocity at 200 cm, m/sec; and n - number of days in the month.

We used this formula in computing the map of evaporation from small reservoirs in the CCP.

Formula (1) is the well-known B.D.Zaykov Formula (Zaykov, 1949) in which the coefficient 0.15 was changed to 0.12.

The basis for changing the coefficient was the above-mentioned comparison of results of computations of evaporation from reservoir surfaces of the Kursk Province made with different methods.

The basic data for the computation of evaporation with Formula (1) are - water surface temperature, absolute humidity at 200 cm above the reservoir, and wind velocity at the same height. We were able to obtain these data by reducing the corresponding meteorological elements of land stations to reservoir conditions utilizing the relationships which we were able to establish between the meteorological elements observed at the meteorological station of the KZIRS and above two reservoirs of the Kursk Province located at a distance of 2 and 25 km from this station. The water surface temperature was, in this case, obtained from the relationship with air temperature.

Usually the relation between air temperature and that of a water surface is represented graphically by two curves, one for the summer and the other - for the fall-Spring months.

By comparing average monthly temperatures of the water surface of our reservoirs (Uspenskoe and Borshchenskoe) and the air temperature at the KZIRS we obtained one straight line expressed by the equation:

$$y = 3+0.93x, \qquad (2)$$

where y - water temperature and x - air temperature.

The coefficient of correlation of this regression is 0.97 and the mean quadratic deviations σ_x and σ_y are correspondingly 4.8 and 4.6 for S_x and S_y (which represent the extent of departure of the points from the straight line regression) 1.2 and 1.1° respectively.

Equation 2 is very close to the formula suggested at one time by B.D.Zaykov for computing temperatures from small reservoirs from air temperature at a land meteorological station (Zaykov, 1949).

M.P.Timofeev in proposing his method of computing the temperatures of the water surface of reservoirs notes that for small reservoirs the equation of the type shown above can be used (Timofeev, 1961).

Already in the 20's of our century, I.V.Molchanov showed on the basis of thermal data for small lakes of the Leningrad Province that during the summer months the average monthly temperatures of the water surface of lakes is 2-3° higher than the air temperature (Molchanov, 1925).

The close relationship which we obtained between the temperature of the water surface of the reservoirs and air temperatures is explained by the fact that we are dealing with small and shallow reservoirs. In such reservoirs (of middle latitudes) the water is well warmed during summer months and its thermal state is close to homothermal. It is therefore sufficient for the upper layer of water to cool to bring forth convectional mixing which with the aid of wind action engulfs the entire mass of water. With the same wind mixing the warming of upper layers is passed on into the depth of the reservoirs. Even when the water mass of the reservoirs at a given instant is divided into thermal zones the temperature of its upper layers is closely related to the air temperature but mixing takes place only in the epilimnion.

Equation (2) made it possible to compute the surface temperatures of small reservoirs from data of the meteorological station network.

In the computation of absolute humidity above the reservoirs from the station network data, we utilized a relationship between the average 10-day values of absolute humidity at the meteorological station of the KZIRS and above our reservoirs. The coefficient of correlation of this relationship proved to be equal 0.99, i.e., practically 1.

The establishment of the relationship between wind velocity at a land station (KZIRS) and on the reservoirs turned out to be considerably more complicated. It is known that the velocity of a wind blowing from the land onto the reservoirs increases and that the greatest changes in wind velocity takes place at the shore because it is here where deformation of the wind profile occurs in connection with the change in the roughness parameter.

It was established from the observations on Krasavitza and Valday Lakes (Braslavskiy and Vikulina, 1954) that in lakes lying in depressions and in narrow river valleys the wind velocity is 10-15% lower than on reservoirs located in an open even area, provided the maximum fetch of the wind does not exceed 1.5-2.0 km. In our case the mean monthly wind velocity at the height of the wind vane of the meteorological station of KZIRS (12 m) located on an open even field was compared with the wind velocity above the Borshchenskoe and Uspenskoe Reservoirs which was measured at the height of 2 m above the water surface 20-30 m away from the shore.

As a result of this comparison we obtained a straight line regression with a coefficient of correlation of 0.75.

Mean quadratic deviations for the x and y arrays turned out to be equal 0.92 and 0.77 for S_x and S_y of 0.60 and 0.50.

The obtained relationship for wind velocity was not as close as in the first two cases (for water temperature and absolute humidity). But, it can still be considered sufficiently dependable and can be utilized in obtaining wind velocity from data of the meteorological station network.

It proved practically possible to adopt a coefficient of 0.85 for converting the wind velocity of the KZIRS meteorological station to that above the reservoirs.

According to the analysis of A.P.Braslavskiy and Z.A.Vikulina (1954) the conversion of wind velocity measured at the height of the wind vane at a land meteorological station in an open even locality to reservoir conditions can be made by applying a coefficient of 1.3. Then to convert the wind velocity above the reservoirs to the 2 m height, still another multiplier 0.8 is applied, i.e., altogether the value of wind velocity at a land station is multiplied by 1.04.

Then, as stated above, for reservoirs lying in the depressions of the relief, in ravines, river valleys, etc. the wind velocity must be further reduced by 10-15%. Therefore, in our case, for reservoirs of the ravine type with a wind fetch not exceeding 2 km it is necessary to apply also this multiplier which in the end results in an overall coefficient of 0.88.

Thus, the method of directly relating wind velocity at the wind vane to that over a lake employed by us gave practically the same results as that obtained by the mentioned authors.

During World War II almost the entire territory under consideration was either in the occupied zone or next to it. Therefore, the meteorological stations did not function here during the war years.

Systematic observations on the station network of the CCP were restored only in 1945-1946.

For this reason we utilized the 1946-1961 period in the preparation of the evaporation map. Having limited ourselves to the indicated 16-year period we evaluated it by comparing mean monthly values of the basic meteorological elements for this period with the corresponding long-term means for 1891-1935. Regrettably, in judging the mean wind velocity it was possible to utilize data from only

two meteorological stations, because long-term data on wind velocity for the CCP are almost entirely lacking.

The information on absolute humidity is also limited (Table 1).

In Table 1 are given the deviations of the 16-year average values of temperatures and humidity from the mean for the long-term period.

It isn't hard to see that on the territory of the CCP the 16-year average air temperature was somewhat higher than the long-term value. The June air temperature was especially high exceeding the long-term mean by 1-2°. Only in October was the 16-year mean temperature 0.3-0.9° lower than the long-term normal.

The 16-year absolute humidity was lower than the long-term mean for all months except August.

As seen in Table 2 the 16-year mean wind velocity on the territory of the CCP was lower than the long-term normal.

From the data of average temperature and humidity it can be expected that the 16-year mean value of evaporation would be higher than the normal. At the same time, the lower wind velocity during this period should tend to decrease evaporation.

Values of evaporation for three stations in the CCP both long-term mean and mean for the considered 16-years and the deviation of the latter from long-term means are shown in Table 3.

The total evaporation for May-October for the stations shown in the table proved practically the same for comparable periods.

But the monthly values of evaporation - the averages for 16 years do not, in all cases, coincide with the long-term mean.

The greatest difference in monthly means is noted in June which is due to the large differences in the mean June air temperatures for the compared periods.

TABLE 1

DEVIATIONS OF THE 1946-1961 MEAN MONTHLY TEMPERATURE AND ABSOLUTE HUMIDITY FROM THE MEAN LONG TERM (1891-1935) VALUES FOR A NUMBER OF METEOROLOGICAL STATIONS IN THE CENTRAL CHERNOZEM PROVINCES

Station	Air temperature °C						Absolute humidity					
	V	VI	VII	VIII	IX	X	V	VI	VII	VIII	IX	X
Kursk	−0.2	+1.3	+0.3	+0.2	+0.2	−0.3	−0.5	−0.6	−0.3	+0.8	+0.1	−0.2
L'gov	+0.5	+1.9	+0.7	+0.9	+0.3	−0.4	−0.3	0.0	−0.4	+1.0	+0.3	−0.2
Oboyan'	+0.2	+1.2	0.0	+0.2	0.0	−0.9	−0.5	−0.6	−0.8	+0.6	−0.1	−0.3
Gotnya	−0.1	+1.7	+0.5	+0.7	0.0	−0.7	—	—	—	—	—	—
Belgorod	−0.3	+1.5	−0.1	−0.3	−0.1	−0.8	−0.3	−0.7	−0.2	+0.7	+0.3	−0.2
Oskol	−0.4	+1.3	0.0	+0.5	0.0	−0.7	—	—	—	—	—	—
Trubachevsk . .	−0.3	+0.9	+0.1	+0.3	+0.1	−0.5	−0.9	−0.2	−0.3	+0.7	+0.2	−0.6
Michurinsk. . .	0.0	+1.5	−0.1	+0.3	0.0	−0.7	−0.5	−0.2	−0.1	+0.9	0.0	−0.6
Tambov	+0.1	+1.5	−0.3	+0.4	+0.1	−0.7	−1.0	−0.7	−0.6	+0.5	−0.2	−0.5
Rossosh'	+0.2	+1.6	+0.2	+0.7	+0.3	−0.9	—	—	—	—	—	—
Sum	−0.3	+14.4	+1.3	+3.9	+0.9	−6.6						
Average . . .	0.0	+1.4	+0.1	+0.4	+0.1	−0.7						

TABLE 2

DEVIATIONS OF 16 YEAR MEAN WIND VELOCITIES FROM THE LONG TERM MEANS FOR METEOROLOGICAL STATIONS OF CENTRAL CHERNOZEM PROVINCES

Station	V	VI	VII	VIII	IX	X	Av. for May-Oct.
Kursk	—0.3	—0.3	—0.4	—0.5	—0.5	—0.3	—0.4
Bogoroditskoe-Fenino.	—0.8	—0.2	0.0	—0.3	—0.3	—0.3	—0.3
Voronezh. . . .	—0.1	—0.5	—0.4	—0.6	—0.8	—1.2	—0.6

TABLE 3

EVAPORATION, mm - LONG TERM AVERAGE, 16 YEAR AVERAGE FOR STATIONS IN THE CENTRAL CHERNOZEM PROVINCES AND DEVIATIONS OF 16 YEAR AVERAGE FROM THE LONG TERM AVERAGE

Station	Period	V	VI	VII	VIII	IX	X	Sum for May-Oct
Kursk	Long-term mean	90	101	122	138	100	46	597
	16-year mean .	91	123	122	121	92	42	591
	Difference . .	+1	+22	0	—17	—8	—4	—6
Bogoroditskoe-Fenino	Long-term mean.	87	102	111	130	90	43	563
	16-year mean .	84	116	117	121	81	38	557
	Difference . .	—3	+14	+6	—9	—9	—5	—6
Voronezh	Long-term mean	92	110	131	143	102	49	627
	16-year mean .	106	142	138	138	95	44	662
	Difference	+14	+32	+7	—5	—7	—5	+35

Therefore, the presented monthly maps of evaporation give normal evaporation from surfaces of small reservoirs of the CCP only for the considered period, while the map of total evaporation (May-October) applies to the long-term normal.

In constructing the evaporation map we selected the period of the greatest rate of evaporation - May to October. To obtain the evaporation value for the entire ice-free period (from the middle of April to the middle of November) 15 mm of evaporation for April and November should be used for the entire part of the CCP lying to the northwest of the 600 mm isoline of evaporation (Fig. 1) and 20 mm for each of these months for the southeastern part.

According to the data of the expedition of the Laboratory of Limnology the monthly distribution of evaporation from small reservoirs in the Kursk Province expressed in percent of the total for April-November is as follows:

Months	April	May	June	July	August	September	October	November
Evaporation, %	3	14	20	22	18	13	6	4

As is seen evaporation for April and November constitute only 3 and 4% of the total.

In this respect the presented data differ considerably from the monthly distribution of evaporation used by the above-named authors who constructed evaporation maps.

In planning and operating reservoirs values of evaporation with frequencies of 3 and 20% are usually employed.

As stated above, K.P.Voskresenskiy (1948) in constructing the evaporation map for the CCP recomputed the normals of V.K.Davydov's evaporation map. To convert to evaporation of 3% frequency he introduced the coefficient 1.25 and for the 20% frequency he used 1.10, for a coefficient of variation of evaporation in the CCP of 0.13.

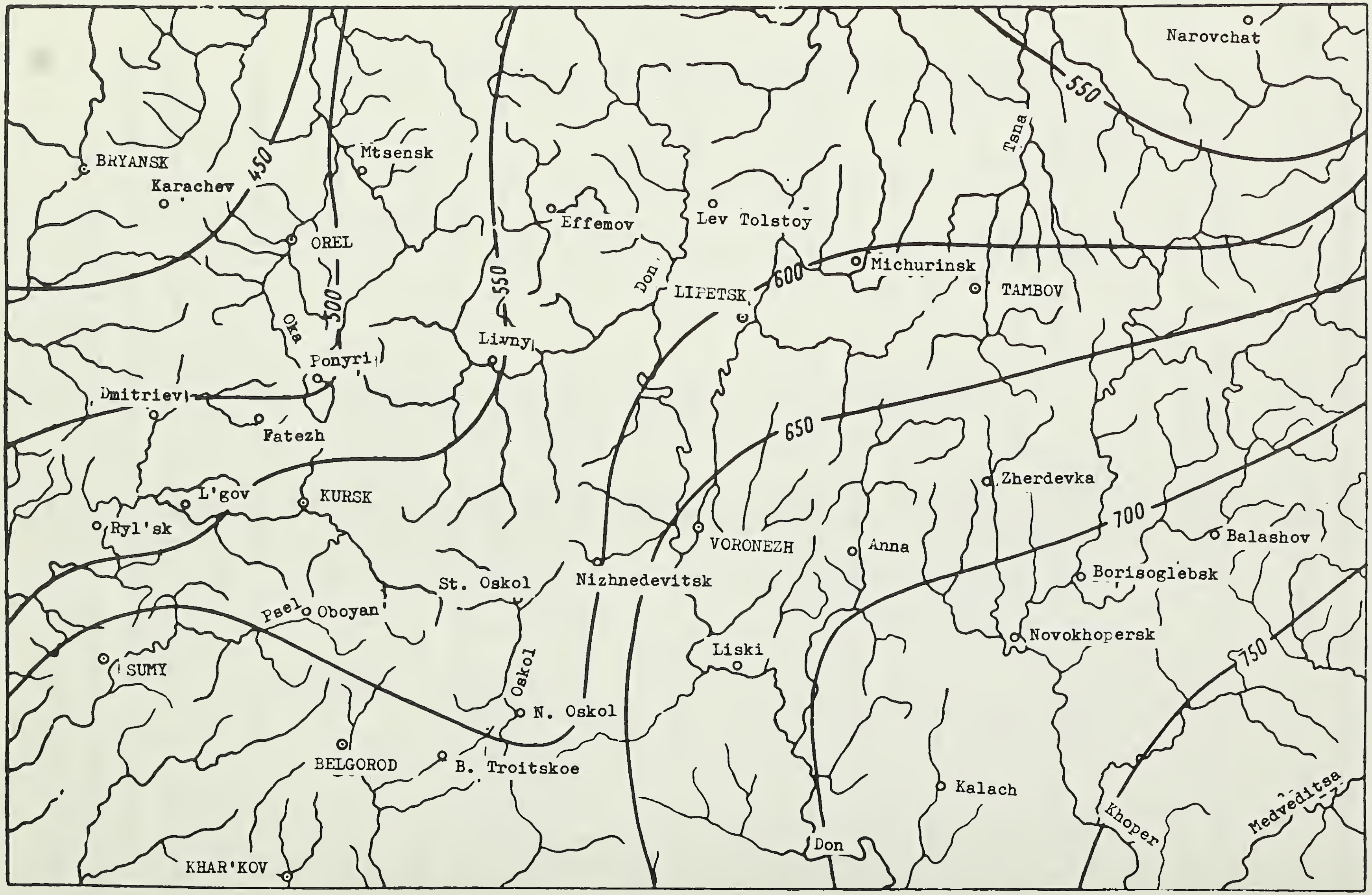

FIG. 1 MAY-OCT. EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

We also computed the corresponding coefficients and obtained 1.25 and 1.12, i.e., practically the same values as used by Voskresenskiy.

The average coefficient of variation of evaporation also turned out to be 0.13 with a range of 0.08 to 0.16.

With these coefficients it is not difficult to obtain from the appended maps the evaporation for the 3% and 20% frequencies.

We constructed evaporation maps not only for the entire period (May-October) but also for each month (Figures 2-7). The constructed maps are based on data from 48 meteorological stations located on the territory of the CCP and from about 20 stations of the surrounding provinces.

The isolines on our map accentuate to a certain degree the orographic characteristics of the locality.

Thus, the 600 mm evaporation isoline passes along the eastern slope of the Mid-Russian Highland dividing the entire territory of the CCP into northwestern and southeastern parts.

In the northwestern part evaporation for May-October ranges from 450 to 600 mm and in the southeastern from 600 to 750 mm.

If the values for April and November are added then the total evaporation for the ice-free period is 480-630 mm for the northwest and 630-790 mm for the southeast.

According to V.K.Davydov's map the evaporation on the territory of the CCP ranges from 500 to 650 mm; on B.D.Zaykov's map from 600 to 750 mm and on the map of A.P.Braslavskiy and Z.A.Vikulina - from 700 to 800 mm.

To utilize our maps in obtaining values of evaporation from the surface of reservoirs which differ in size from those used by us in constructing the maps we made use of the data of A.P.Braslavskiy and Z.A.Vikulina (1954).

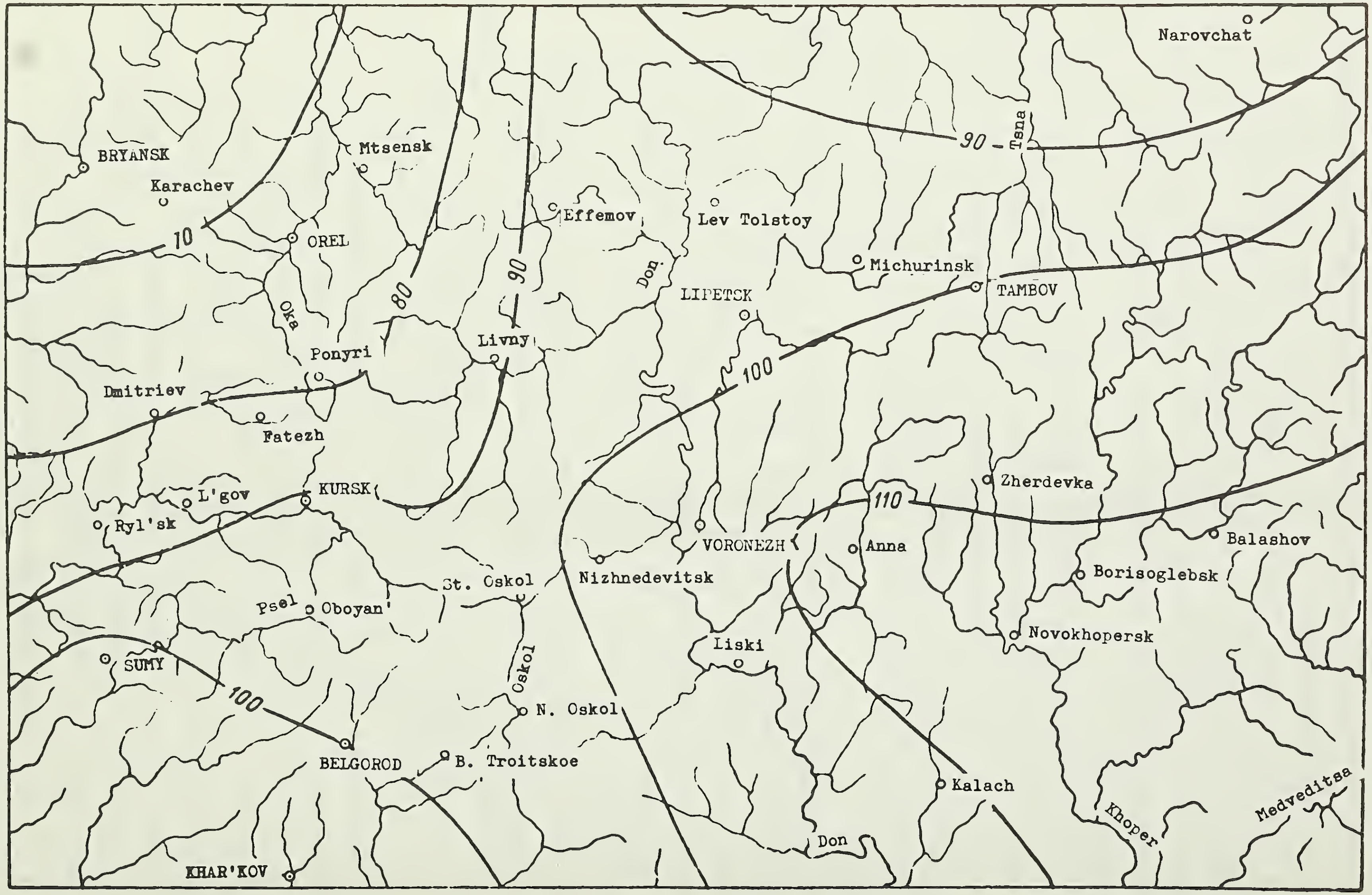

FIG. 2 MAY EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

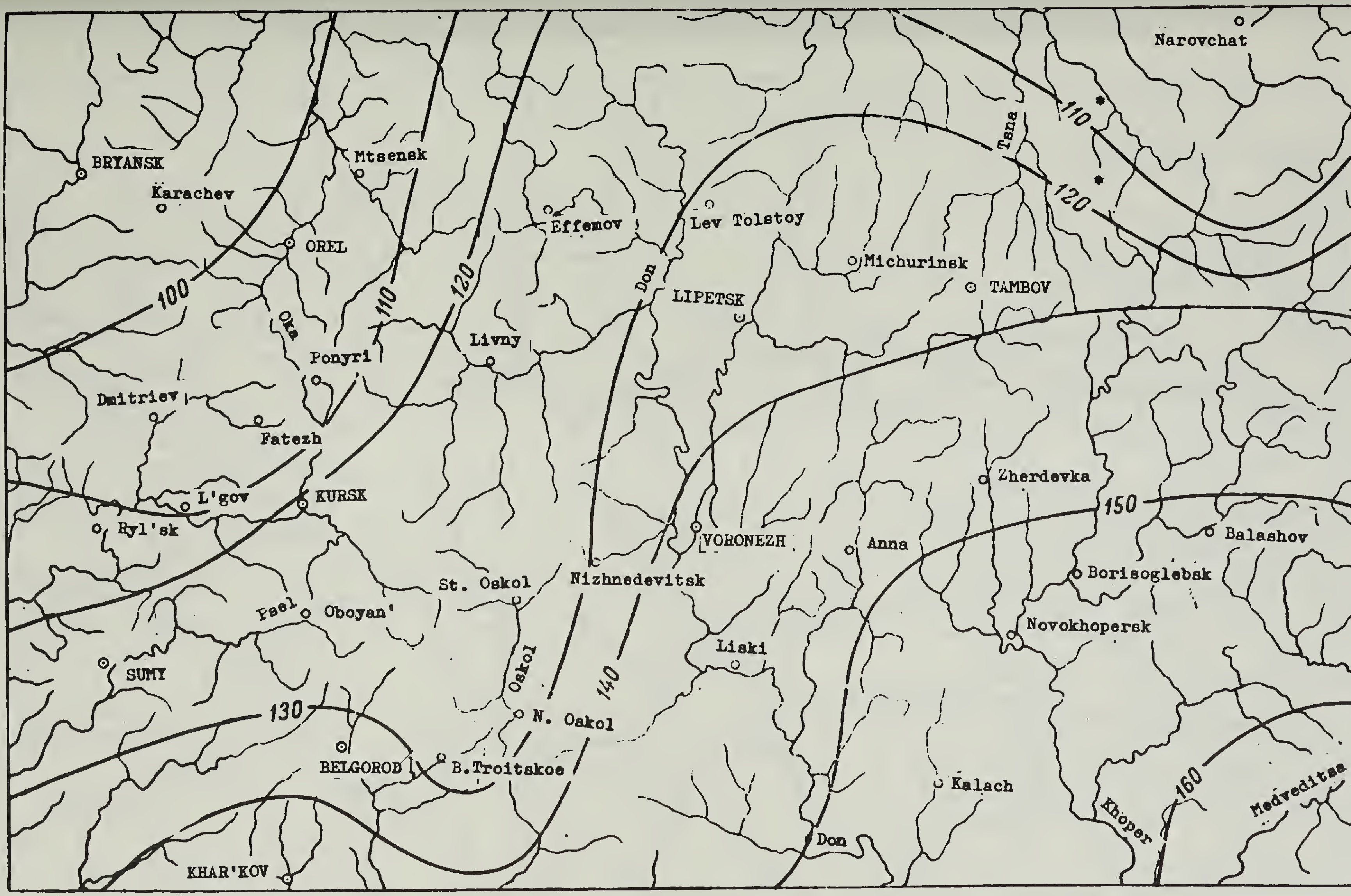

FIG. 3 JUNE EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

* These are obviously misprints, they should be 130 and 120. (Translator's Note).

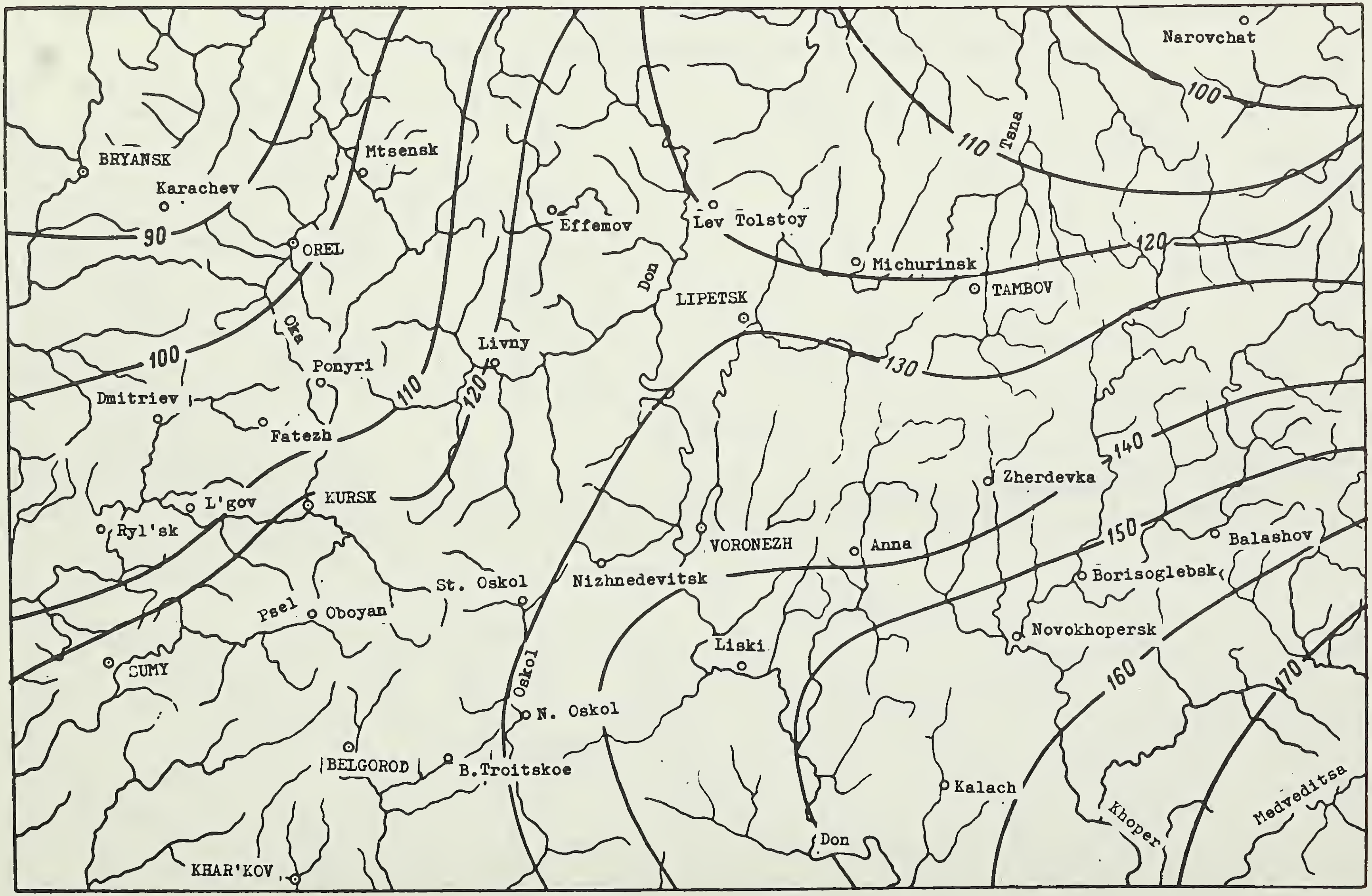

FIG. 4 JULY EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

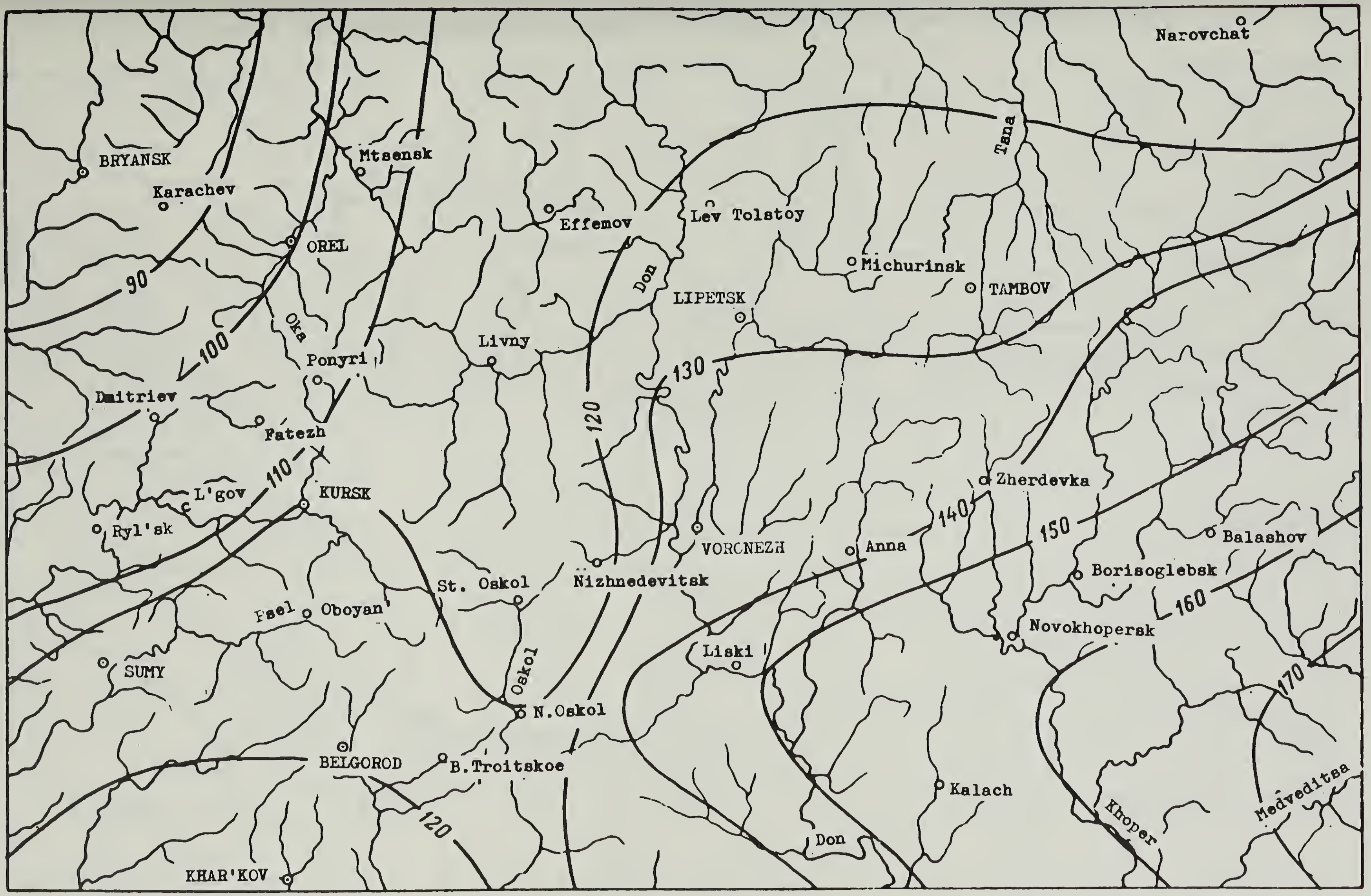

FIG. 5 AUGUST EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

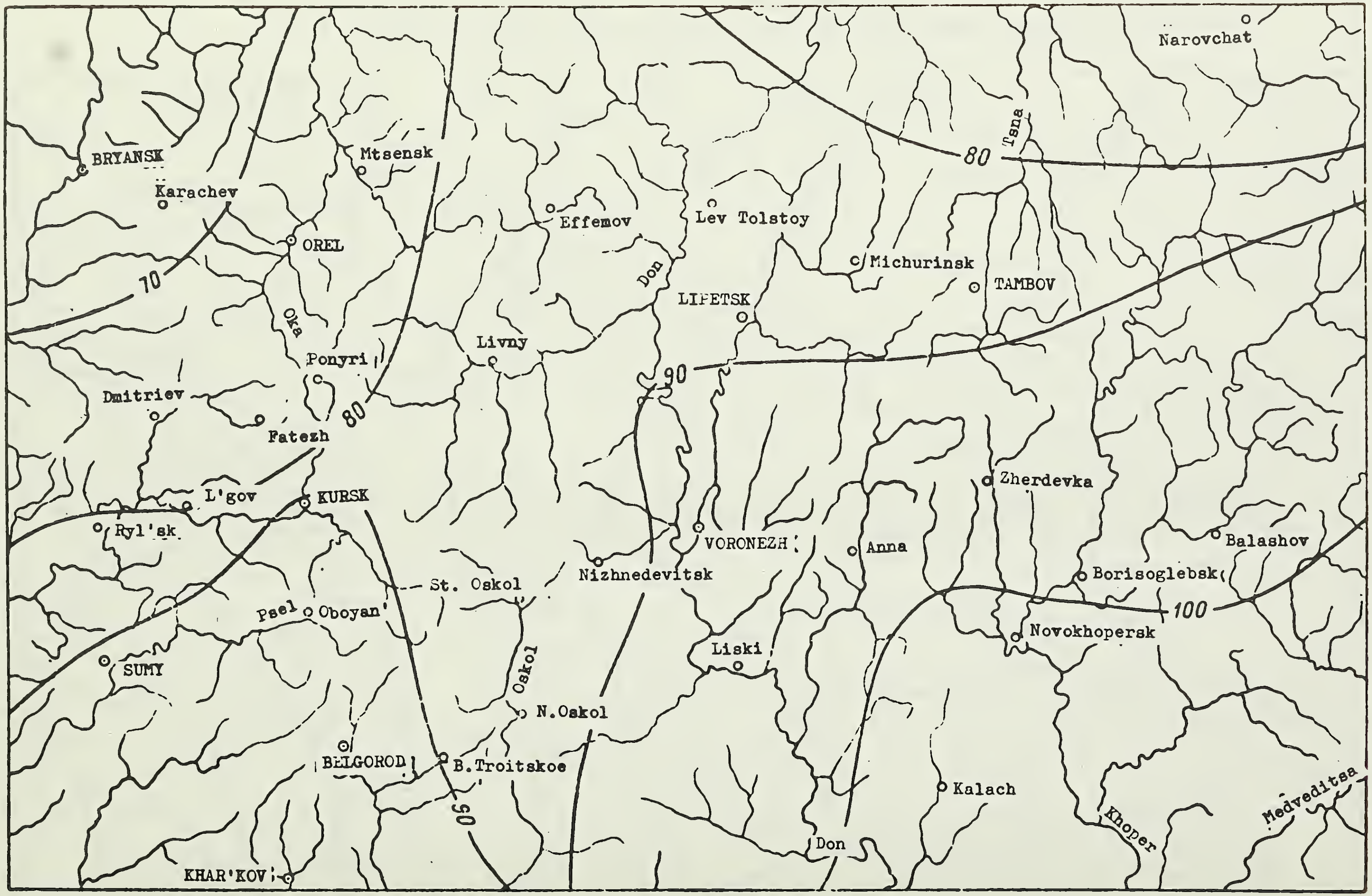

FIG. 6 SEPTEMBER EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

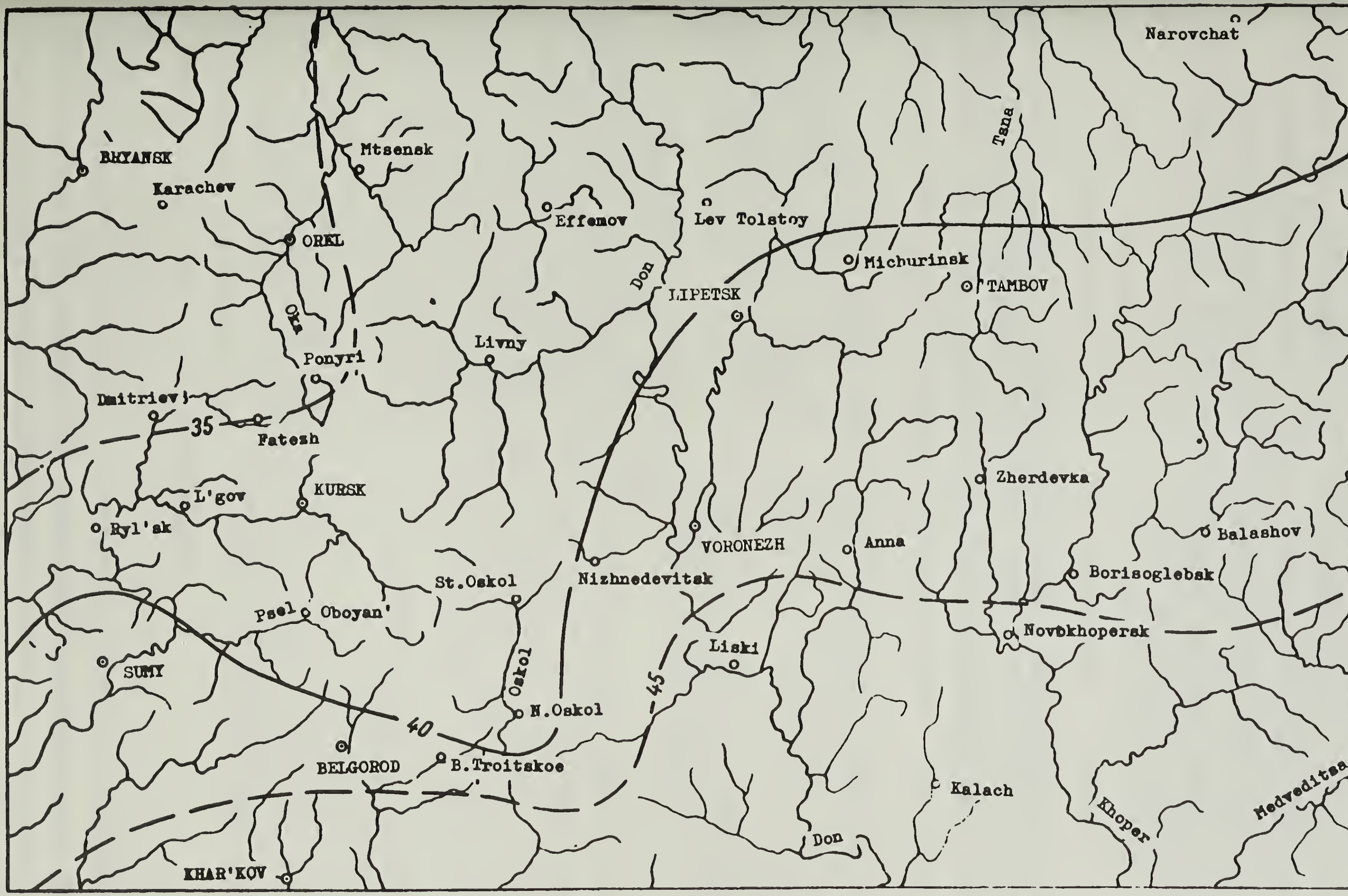

FIG. 7 OCTOBER EVAPORATION (mm) FROM SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

The mentioned authors developed coefficients for the different geographical zones of the Soviet Union.

Using their coefficients for the forest-steppe belt we recomputed them, assigning unity to the evaporation values from reservoirs similar to those considered by us, i.e., having an average depth of 2-5 m and an average wind fetch of 1-2 km (Table 4).

TABLE 4

RATIOS OF EVAPORATION VALUE

On reservoirs of different sizes, km						On reservoirs with different average depth			
1	5	10	20	50	100	2	5	10	15
1.00	0.988	0.958	0.944	0.941	0.939	1.00	0.976	0.960	0.946

For an open reservoir the values taken from our map must be increased by 10-15%. For a forested reservoir but lying in a ravine, the value of evaporation would be by 10-15% less than for a reservoir of the ravine type with unforested shores (Forsh, 1961).

In conclusion, it can be said that the proposed evaporation map must be used only as a guide in obtaining values of evaporation from surfaces of reservoirs in the CCP since in every individual case, the values shown on the maps can deviate one way or another depending on local conditions. Moreover, the accuracy of calculations of evaporation with Formula (1) lies within a range of ±10% (Zaykov, 1949).

The coefficients for converting evaporation to the 3 and 20% frequency given in the paper are useful in practical application of the maps.

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I. Ya. D E G O P I K

HYDROCHEMICAL CHARACTERISTICS OF SMALL RESERVOIRS IN SOME DISTRICTS OF THE CENTRAL CHERNOZEM PROVINCES

Our investigations were carried out in 1956-60 as a part of the expedition of the Laboratory of Limnology for the study of processes of silting of small reservoirs and of accompanying phenomena.

In the main, the reservoirs of the Kursk Province were investigated. On the inter-river area between the Seym and Psel Rivers 18 reservoirs were investigated which are located in the Ivaninskiy, Korenevskiy Bol'she Soldatskiy, Streletskiy, Oboyanskiy, and the L'govskiy Districts. In the Orel Province 4 reservoirs were investigated, in the Mtsensk, Orel and Kromskiy Districts.

As far as is known to us, hydrochemical studies of ponds in the Central Chernozem Provinces (CCP) were published by P.P.Voronkov in his monograph (1955) and by I.M.Rozinoer (1960) for the reservoirs of the Voronezh Province.

Brief Description of the Physical-Geographical Conditions

The CCP are in one landscape zone - the forest-steppe zone. At the present time, the steppes are almost entirely cultivated and the greater part of the forests are cleared. The territory of the CCP is a plain with a dissected relief. The vegetation grows principally on the slopes of the ravine- gully net. Medium podzolized and leached chernozem soils predominate.

The area which we investigated in greatest detail lies in the Sudzhenskiy District of the sub-zone of the forest steppe and is a part of the southwestern slope of the Mid-Russian Highland. The parent material consists of upper chalk marls and pure white chalk covered on the watershed divides by sandy loam tertiary deposits and by loess-like loams. The district contains contemporary karst

(Mil'kov, 1957). Thanks to the relatively humid climate the soils of the catchments of the CCP are well leached of the readily soluble inorganic compounds. This causes the formation of poorly mineralized bicarbonate-calcium soil- and surface water. The subsoils of the catchments are also well leached (Voronkov, 1955).

According to the data of a number of investigators (Dubyanskiy, 1948, 1955; Elfimov, 1957; and Sedykh, 1960, 1961a, 1961b, and 1961c) carbonate-calcium waters, which in various combinations with other types are encountered in all water-bearing horizons, are the most prevalent type of underground waters of the CCP. In the upper horizons (in the zone of active water exchange) they are the principal ones. The underground waters are generally fresh and only some of them are salinized.

The comparative uniformity of physical-geographical conditions makes it possible to expect a general regularity in the forming and in the regime of the ion composition in the water of ponds.

We have at our disposal data of detailed observations on the hydrochemical regime of two typical reservoirs and data for two other reservoirs which were investigated in lesser detail. In addition, a one-time analysis of water samples characterizing the summer period was made on 18 reservoirs.

Of the principal reservoirs selected the Borshchenskoe Reservoir built in 1950 is located in the lower reaches of Borshchen' Creek - a left tributary of the Reut River. This flowing reservoir has two earth spillways and a siphon. The flow is maintained throughout the entire year and ceases only occasionally - in the winter during freezing and in the summer when dry weather and high air temperatures are sustained over a prolonged period. The surface area is about 35 ha, the water volume is $654 \cdot 10^3 m^3$, and the

average and maximum depths are 2.1 and 5.6 m. The 36.7 km^2 catchment area is almost completely cultivated.

The Uspenskoe Reservoir was built in 1953 on the Rzhavets Ravine (Dichnya River). Unlike the Borshchenskoe Reservoir it is designed for complete storage of surface water. The reservoir is formed by a solid dam with a siphon located somewhat below the confluence of two large ravines which are dry during the summer. Flow occurs principally during the Spring high water and occasionally after prolonged copious rains in the fall and in the summer. The surface area is about 66 ha, the water volume 243 $\cdot$ $10^3 m^3$, the average depth is 3.7 and the maximum 10.1 m. The 33.2 km^2 catchment area is almost completely cultivated. The upper part of the right ravine is covered with dense brush.

The pond on the Berezovaya Ravine is formed by a dam built in 1952 on one of the tributaries to the Borshchenskoe Reservoir. Runoff occurs during the Spring and at time of occurrence of heavy precipitation. The pond is small, the surface area being 1.2 ha, the water volume is 14.4 $\cdot$ $10^3 m^3$, the average depth is 1.3 and the maximum 3.5 m. The catchment area is 1.22 km^2, the slopes of the ravine are forested.

The pond in the V.V.Alekhin Central Chernozem Reserve lies on a dry, sparsely forested ravine within an uncultivated virgin steppe. The ravine on which the pond was constructed in 1951 is part of the Melovat River Basin. The pond is small, surface area 0.5 ha, water volume 7.2 $\cdot 10^3 m^3$, the average depth is 1.3 and the maximum 3.4 m. The catchment area is 1.29 km^2.

The selected principal ponds therefore represent ponds designed for complete storage. They have emergency spillways and are equipped only with siphons.

The investigated reservoirs are in different landscape conditions. In addition, the amount of precipitation, the duration of the snow melting period and the high water

flows which are of great importance in the forming of the mineralization and of the chemical composition of the water feeding the pond differed during the period of investigation.

The ages of all but two of the ponds on which the one-time sampling of the water was carried out ranged from 8 to 10 years. The exceptions were the ponds in Kukuevka of the Streletskiy District (31 years) and in the Vyshnie Dereven'ki in the L'gov District (28 years). The surface areas of the investigated ponds ranged from 2 to 25 ha, the catchment area from 1 to 34 km^2. The catchment areas are generally cultivated, the forest cover on some ranges from 1 to 50%. A more detailed description of these ponds is given in the paper by I.N. Sorokin and L.V. Yakovleva (1961).

Content of Dissolved Gases and the Active Reaction of the Water

The content of dissolved gases in the water of the ponds is subject to large variations.

In the first years of existence of the reservoir an absorption of the dissolved oxygen and a simultaneous increase in the content of carbon dioxide take place in the process of mineralization of the considerable vegetation.

The rate of these processes gradually diminishes and a certain equilibrium in the gas regime characteristic of a given reservoir is established. However, it can be disturbed by a large inflow into the reservoir of biochemically active substances.

Changes in the composition of dissolved gases occur not only seasonally but also within short periods of time and take place differently depending on the dynamic conditions of the water masses of the ponds (Forsh, 1963).

We have previously described in detail the gas regime of the two main reservoirs - the Borshchenskoe (Degopik, 1960) and the Uspenskoe (Degopik, 1963) Reservoirs.

We pointed out that with an open water surface the basic factors determining the distribution of gases are the wind regime, the water temperature and the bloom. During the growing season on sunny calm days when a clearly expressed temperature stratification occurs, the intensive development of aquatic vegetation causes blooming and in individual cases the oxygen content in the surface layer reaches 260% of saturation and the pH rises to 10.5 The water mass above the discontinuity layer is characterized by the absence of carbon dioxide, by the presence of monocarbonates, by supersaturation with oxygen and by an alkaline reaction. In the discontinuity layer the oxygen content is sharply reduced, there appears carbon dioxide, the quantity of which increases towards the bottom, the pH value decreases and the reaction of the water is close to neutral. The difference between the oxygen content in the surface and the bottom layers reaches 22 mg/lit. due to the expenditure of oxygen in the layers near the bottom (saturation less than 10%) and to supersaturation of the surface layers caused by blooming.

A less sharply expressed stratification due to wind mixing is, however, more typical for the growing season. Dynamic phenomena of wave action in the water mass produced by the wind act to depress the development of phytoplankton and lead to the reduction in the content of dissolved oxygen, the occurrence of carbon dioxide and the lowering of the pH on the one hand, and on the other hand, they equalize the non-uniform distribution of content of gases in the reservoir. A small supersaturation, or even more frequently, a deficit of oxygen saturation is observed in the upper layer. In the deeper part of the reservoir, near the dam, the reduction in oxygen saturation with depth takes place gradually without sharp jumps. In the shallow parts an equalization in the content of gases in the entire water mass takes place with wind mixing.

Wind mixing exerts a greater influence on the vertical distribution of dissolved gases and of pH in reservoirs with a relatively large surface area and with gently sloping banks such as the Borshchenskoe and Uspenskoe Reservoirs and a lesser effect in reservoirs with small surface areas and relatively high (the pond in the sanctuary) or forested banks (the pond in the Berezovaya Ravine). Figure 1 represents the distribution of the content of dissolved gases and of pH for an ice-free surface of the mentioned reservoirs.

During the ice period when there is no aeration of the water a depletion of oxygen, an increase in carbon dioxide and a drop in the pH take place due to the oxidation of organic substances and the vital activity of aquatic organisms. These processes take place in the reservoirs at different rates and in individual cases lead to a considerable absorption of oxygen.

During the ice period, there occurs also a photosynthesizing activity of winter forms which is conducive to a relatively high oxygen content in the layers of the water under the ice.

On the Uspenskoe Reservoir we observed a considerable oxygen deficit in the surface layer (close to 40% of saturation), some increase in the oxygen content at about the 2 m depth (60%) and a sharp decrease at depths greater than 4 m. In 1959 there was an oxygen saturation close to 100% and in some points, up to 110% in the surface layer down to 2 m. At depths greater than 4 m, the oxygen saturation dropped sharply as in 1960. Apparently in 1960 the increase in the oxygen content in the layer of about 2 m was caused by the poor development of phytoplankton, and in 1959 by a quite intensive one which exerted a considerable influence on the gas content in the water layer under the ice.

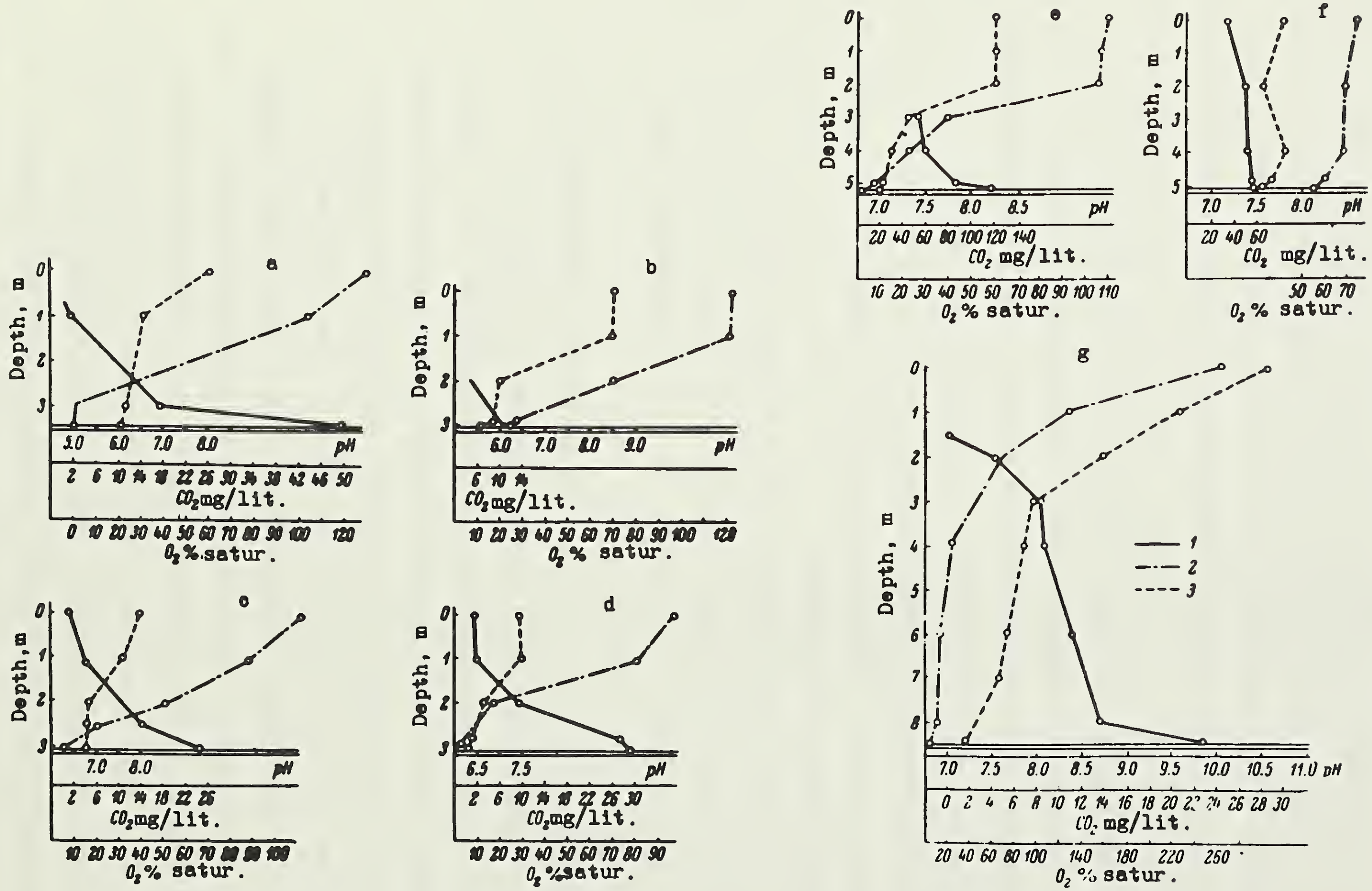

FIG. 1. Vertical Distribution of the Content of Gases and of pH in Ponds During the Summer Period

a - In the sanctuary, 15 July, 1956; b - same place 22 Aug., 1956; c - In the Berezovaya Ravine, 13 July, 1956;

d - Same place 18 Aug., 1956; e - Borshchenskoe Reservoir, 2 Aug., 1956; f - Same place 26 Aug., 1956;

g - Uspenskoe Reservoir, 20 July, 1960. 1 - CO_2; 2 - O_2; 3 - pH

I.M.Rozinoer (1960) who investigated ponds in the Voronezh Province also observed the accumulation of oxygen in the surface layer resulting from photosynthesis both in the summer and in the winter and notes about the same regime of dissolved gases.

Mineralization and Chemical Composition of Pond Water

The Borshchenskoe and Uspenskoe Reservoirs have a weakly expressed uniform hydrochemical regime during all seasons of the year (Degopik, 1961, 1962, 1964). With respect to the ion content they belong to the bicarbonate-calcium waters (Alekin, 1953). Only the degree of the manifestation of bicarbonate and the value of mineralization change. The bicarbonate nature is expressed more sharply in the winter (up to 94%) and least of all after the passing of high water (up to 57%). The change in the value of mineralization occurs mainly due to the content of bicarbonate of calcium. The increase in mineralization and in the bicarbonate nature is due to the inflow of ground water. With the development of high water and depending on its character the mineralization of the water decreases (less than 100 mg/lit), and so does the relative content of bicarbonate ions.

In the Uspenskoe Reservoir the mineralization of the water during the winter low water during the investigated period does not exceed 275 mg/lit.

After the passage of high water the mineralization dropped to about 145 mg/lit., the relative ion content of the water remaining the same with an expressed bicarbonate character which is typical of the winter low water. In 1960 the mineralization of water was less than 100 mg/lit. and had a less expressed bicarbonate character (57-77%).

In the Borshchenskoe Reservoir the mineralization of water during the winter low water reached 530 mg/lit. and

after the passing of high water (in 1957) was of the order of 200 mg/lit., the relative HCO_3 ion content having decreased from 88 to 65%. The reduction in the relative content of bicarbonate ion is due to the inflow during the flood of waters with a relative high content of SO_4^{--} ions, the origin of which is connected with the washing-out of the surface layer of the soil of products of mineralization of vegetal and animal residue (Voronkov, 1955).

During the passing of high water in the Uspenskoe Reservoir we observed a spotted picture of the distribution of mineralization and of the relative ion composition of the water. It is interesting to note a "reverse" distribution of mineralization, i.e., when the bottom layers are mineralized less than the upper ones. This occurred after the Spring high water on the Uspenskoe and Borshchenskoe Reservoirs and in the latter also during summer rain floods. Rain floods as well as high water have relatively higher contents of sulphate ions.

Summer hydrochemical investigations on the Uspenskoe Reservoir were carried out over a five-year period beginning in 1956. During this period mineralization of the water ranged from 115 to 206 mg/lit. in the upper layer and from 125 to 240 mg/lit. in the bottom layer. The relative ion content remains stable and was of the bicarbonate class of the Ca^{++} group predominantly of Type II and less frequently of Type I (in the bottom layer) with a sharply expressed bicarbonate character (87-96%). The increase in mineralization and in the carbonate nature of the water after the high-water period is due principally to the inflow of ground water. According to our data the mineralization of the underground water of the first water-bearing stratum does not, in the main, exceed 600 mg/lit and this water belongs predominantly in Types I and II of the bicarbonate-calcium waters.

In the Borshchenskoe Reservoir the summer hydrochemical investigations were carried out also since 1956 but during three years. As we pointed out the Borshchenskoe, unlike the Uspenskoe Reservoir has a constant flow in the channel of the Borshchen' River and the summer rain floods produce in it an active water exchange such as occurred in 1956 as a result of heavy precipitation during a short period of time. In 1957, on the contrary, precipitation was below normal, the flow of water in the Borshchen' River channel was small and during the summer there was no natural discharge from the reservoir, i.e., there was a typical summer low water. 1958 was an intermediate year. Extreme values of mineralization during the investigated years were 185 and 342 mg/lit. during the summer period. The change in mineralization did not lead to changes in the relative ion composition which remained the same in both a typical low-water period as well as in a period of active summer water exchange. The water belongs in the bicarbonate class of the Ca^{++} group of Type I. The mineralization of the Borshchen' River for this period ranged from 229 to 673 mg/lit. and also belonged in the bicarbonate-calcium waters of Type I.

The appearance of alkalinity is due apparently to the presence of a zone of absorbed sodium in the soil layer of this part of the forest-steppe zone (Voronkov, 1956).

The different rate of leaching of individual soil layers is manifested in the wide (from 464 to 1,000 mg/lit.) ranges in the mineralization of the waters of wells and of bore holes. Their ion composition is also subject to a considerable change which increases the bicarbonate manifestation from 43 to 94%. For the most part, however, the water belongs in the carbonate class of the calcium group of the first and second types. The alkalinity occurs with mineralization higher than 600 mg/lit.

Analyzing the hydrochemical regime of two reservoirs typical of the investigated districts and differing in their water balance we see that the outflow and the inflow from a small catchment does not introduce differences in the forming of the mineralization and of the ion composition of the water. Year to year changes connected with different climatic and hydrometeorological and other fluctuations affect only the values of mineralization within definite relatively narrow limits which are defined on the one hand by the mineralization of flood waters and, on the other, by the maximum values of mineralization of low-water water which, in turn, are limited by a relatively low mineralization of the ground water of this zone.

For the selected two main reservoirs we have data on mineralization and on ion composition of water which are shown in Table 1 and in Figure 2. Here, as well as in our above-mentioned papers, we used the graphical method proposed by T.B.Forsh (1957) which reflects the absolute values of the general mineralization, the amount of each component, the relative ion composition and the numerical ratio between the ions which are of great importance in the study of the forming of the chemical composition of natural waters.

Both ponds contain poorly mineralized bicarbonate-calcium water, but differ somewhat in the value of mineralization and in the relative ion composition. The pond in the sanctuary maintains the mineralization and ion composition of water established after the Spring high water. The part of ground feeding is apparently not great and in the last analysis exerts an unimportant influence on the hydrochemical regime. Thus, in July, 1956 there was a clearly expressed influence of ground feeding in the deeper parts of the reservoir, in the bottom layer near the dam, while in the surface water layer and in the shallower parts, the mineralization

Table 1

MINERALIZATION AND CHEMICAL COMPOSITION OF POND WATER IN THE SANCTUARY AND IN THE BEREZOVAYA RAVINE

Date	Place of Sampling	Depth of Sampling	pH	Cations (% mg-equiv.) Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	Anions (% mg-equiv.) Cl^{-}	SO_4^{2-}	HCO_3^{-}	Cations (mg/lit.) Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	Anions (mg/lit.) Cl^{-}	SO_4^{2-}	HCO_3^{-}	Sum of ions mg/lit
Pond on the Central Chernozem Sanctuary																
1956 15 VII	At dam, middle of pond, depth 3–4 m.	Surface	8.03	57.6	25.4	17.0	11.9	30.5	57.6	6.9	1.9	2.5	2.4	8.7	20.8	43.2
		Near Bottom	6.06	57.2	15.3	27.5	2.4	9.9	87.7	15.1	2.5	9.0	1.0	6.3	70.2	104.1
22 VIII	Same place	Surface	8.54	63.8	19.2	17.0	6.4	31.9	61.7	6.1	1.1	2.0	1.1	7.2	17.7	35.2
		Near Bottom	6.78	63.5	15.7	20.8	6.3	27.0	66.7	8.1	1.3	3.2	1.2	8.2	25.6	47.6
15 VII	Head of pond, depth 0.5 m	Surface	7.98	62.3	35.8	1.9	5.5	28.3	66.2	6.7	2.4	0.3	1.0	7.2	21.4	40.0
		Near Bottom	6.97	61.5	25.0	13.5	3.9	26.9	69.3	6.5	1.6	1.8	0.7	6.7	22.0	39.3
22 VIII	Same place	Surface	8.60	72.0	16.0	12.0	6.0	36.0	58.0	7.3	1.0	1.5	1.1	8.7	17.7	37.3
		Near Bottom	7.97	70.0	18.0	12.0	6.0	32.0	62.0	7.1	1.1	1.5	1.1	7.7	19.0	37.5
1959 24 VII	At dam, middle of pond, depth 2.6 m	Surface	7.00	69.5	30.5	0.0	10.9	21.7	67.4	9.8	1.7	0.0	1.8	4.8	18.9	37.0
		Near Bottom	6.74	63.1	19.7	17.2	2.0	7.0	91.0	47.0	5.8	10.5	1.8	8.2	135.5	208.8
Pond in the Berezovaya Ravine																
1956 13 VII	At dam, middle of pond, depth 4.3 m	Surface	7.92	82.0	13.0	5.0	2.7	13.9	83.4	23.9	2.2	2.0	1.6	9.6	73.9	113.2
		Near Bottom	6.80	86.6	10.9	2.5	1.4	2.5	96.1	49.3	3.8	1.8	1.4	3.4	166.5	226.2
18 VIII	Center of pond, depth 2.8 m	Surface	7.48	81.0	14.5	4.5	2.5	13.2	84.3	25.7	2.8	1.8	1.4	10.1	81.1	122.8
		Near Bottom	6.38	82.7	16.3	1.0	2.9	5.8	91.3	34.5	4.2	0.5	2.3	5.8	115.3	162.6
18 VIII	Head of pond, depth 0.8 m	Surface	7.67	81.9	13.1	5.0	2.5	12.0	85.5	26.3	2.6	2.0	1.5	9.1	83.5	125.0
		Near Bottom	7.25	87.3	10.8	1.9	2.5	11.5	86.0	27.5	2.1	0.8	1.5	8.4	82.4	122.7
1957 3 VII	From bridges	Surface	—	80.0	15.0	5.0	3.5	15.0	81.5	32.1	3.6	2.5	2.5	14.4	99.4	154.5
3 VII	Spring at right bank	--	—	87.8	6.6	5.6	1.3	2.6	96.1	93.8	4.2	7.5	2.5	6.7	312.4	427.1
1958 18 VIII	At dam, middle of pond, depth 3.4 m	Surface	7.58	85.1	6.1	8.8	4.8	11.4	83.8	38.9	1.7	5.0	3.9	12.5	116.5	178.5
		Near Bottom	7.04	78.8	5.1	16.1	1.7	7.2	91.1	46.1	1.8	11.8	1.8	10.1	162.3	233.9
28 III	Melt water on left bank of Berezovaya rav.	—	—	44.7	9.4	45.9	2.4	70.6	27.0	7.6	1.0	9.8	0.7	28.2	14.0	61.3

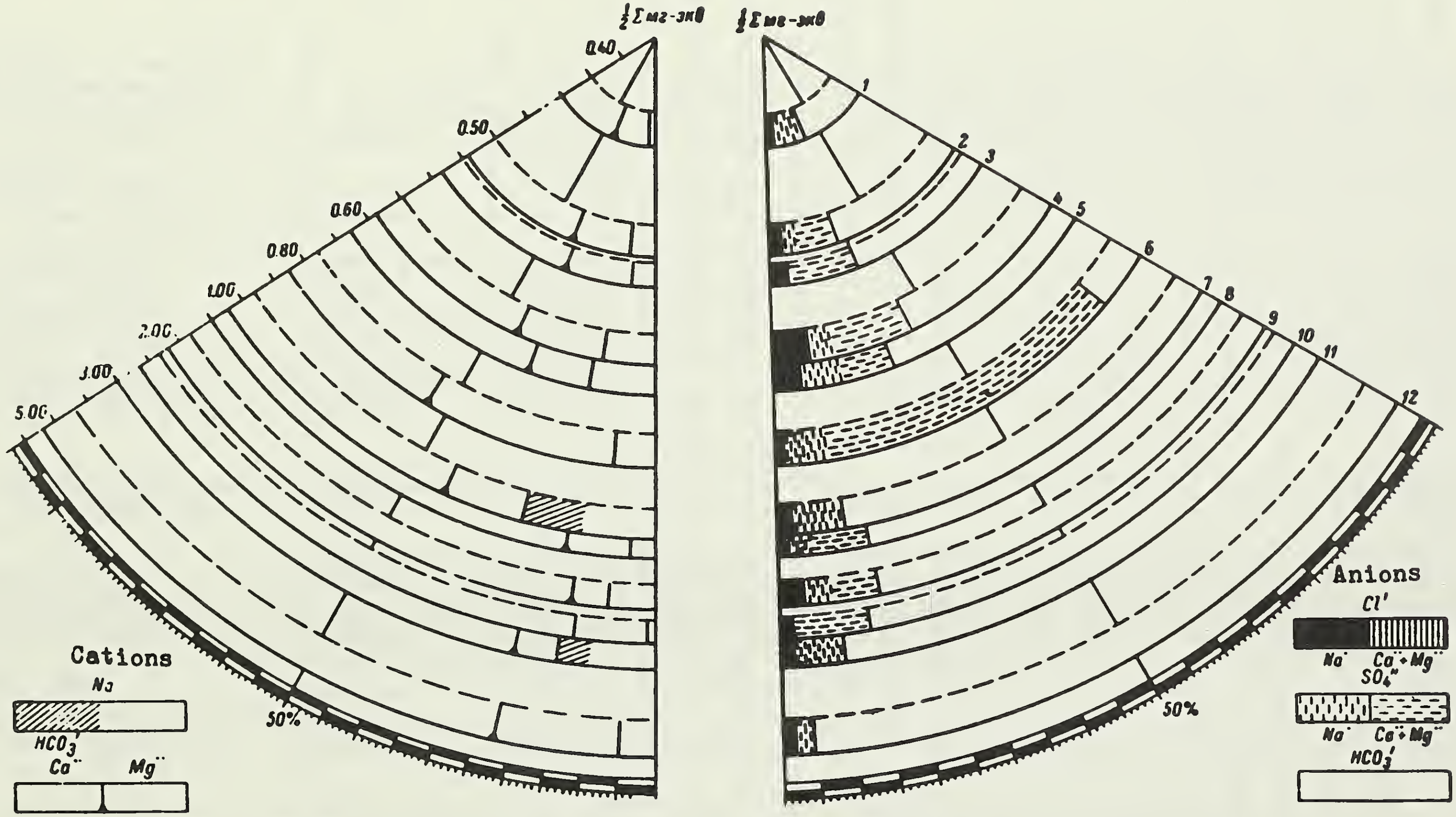

FIG. 2. Ion Composition of the Water of Ponds in the Sanctuary and in Berezovaya Ravine

1 - In the sanctuary 22 Aug., 1956, at the dam, surface; 2 - same place, 15 July, 1956 upper end, near bottom; 3 - same place, 15 July, 1956, upper end, surface; 4 - same place, 15 July, 1956, at the dam, surface; 5 - same place, 22 Aug., 1956, at the dam near bottom; 6 - melt water along the left slope of the Berezovaya Ravine, 28 March, 1958; 7 - in the sanctuary, 15 July 1956 at the dam near bottom; 8 - in the Berezovaya Ravine 13 July, 1956, at the dam, surface; 9 - same place, 18 Aug., 1956 at the dam, surface; 10 - same place, 13 July, 1956, at the dam near bottom; 11 - same place, 18 Aug., 1956, at the dam, surface; 12 - spring in the Berezovaya Ravine, 3 July, 1957.

was about 40 mg/lit. with a strongly expressed bicarbonate character (58-70%) and a relatively high SO_4^{--} ion content which is typical for the high-water period in the forest-steppe zone, the mineralization in the bottom layer increased more than two-fold (104 mg/lit.) and the relative content of HCO_3^- increased. Notable also is the difference in the cation composition. In the bottom water the Na^+ ion content is relatively high and is of Type I, while in the surface layer there is a relative increased content of Mg^{++} ions.

The differences between the surface and bottom layers are due to the relatively high stability of the water mass in the deeper parts of the pond. Subsequently, when the entire water mass is encompassed by mixing this difference is smoothened out, and the characteristics of high-water water are acquired. Thus, in August of the same year the observed mineralization of the bottom layer was only 48 mg/lit., its ion composition also changed - the relative content of sulphate ions was increased and the content of alkaline ions was decreased. The same phenomenon as in 1956 was observed also in July, 1959.

The pond in the Berezovaya Ravine has a somewhat higher mineralization (about 100 mg/lit.) than the pond in the sanctuary, and an expressed bicarbonate character (84-96%). Here also the water mass is relatively stable and the bottom layers of the deeper parts have a higher mineralization (163-240 mg/lit.), and a more clearly expressed bicarbonate character which are due to ground-water feeding. The latter exerts a considerable influence on the hydrochemical regime of the reservoir and masks the influence of the territorial peculiarities. As we pointed out the pond is forested so it is natural to expect some increase in the relative content of sulphate ions. This is confirmed by the analysis of the March, 1958 melt waters from the slopes of the ravine. The relatively low mineralization of the pond water is apparently due to the small part played

by ground water in the feeding of the pond. The spring at the right slope serves to characterize the ground water. Its mineralization is 427 mg/lit. and the water has a sharply expressed bicarbonate character (96%).

As was already pointed out above, we carried out in addition to the investigation on the selected principal reservoirs also analysis of water samples from a number of other ponds during the summer low-water period when it can be expected that maximum values of mineralization for a given reservoir are reached. The mineralization and ion content of these ponds is shown in Table 2 and Figure 3.

With respect to mineralization and the relative ion composition they do not differ from our basic four reservoirs. The extreme values of mineralization are 62 and 546 mg/lit. with the greatest number of investigated ponds having a narrow range of mineralization (150-250 mg/lit.). In the ion composition the water belongs in the bicarbonate class of the calcium group of Types I and II. An exception is the pond in Village Bashkatovo of the Oboyanskiy District which has bicarbonate-sodium water. A relatively large number of Na^+ ions (42%) is contained also in the water of the pond in the Village Murinovka of the Korenevskiy District. Obviously in both ponds ground feeding plays an important role in the water exchange (water mineralization of the ponds is 278 and 377 mg/lit. and the bicarbonate is correspondingly 88 and 93%) and the increase in the Na^+ ion content is connected with the exchange-adsorption phenomena occurring in the relatively weakly leached soil (Voronkov, 1955).

In ponds with a mineralization of about 100 mg/lit. the bicarbonate character is expressed less clearly and the relative SO_4^{--} ion content is correspondingly increased. In them as in the ponds in the sanctuary the water of the Spring high water is maintained. The ponds at Durovka and

TABLE 2

MINERALIZATION AND CHEMICAL COMPOSITION OF POND WATER IN THE KURSK PROVINCE IN THE SUMMER

Date	Location of pond	Cations (% mg-equiv.)			Anions (% mg-equiv.)			Cations (mg/lit)			Anions (mg/lit)			Sum of ions mg/lit
		Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	Cl^{-}	SO_4^{2-}	HCO_3^{-}	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	Cl^{-}	SO_4^{2-}	HCO_3^{-}	
1957 3 VII	Durnovka, Ivaninskiy Dist.	52.0	19.7	28.3	1.2	2.6	96.2	70.9	16.3	48.2	2.8	8.6	399.6	546.4
1958 29 VII	Durovka, Korenevskiy Dist.	68.1	14.9	17.0	4.3	36.2	59.5	12.8	1.7	4.0	1.4	16.3	34.2	70.4
29 VII	3 km from Kremyannoe Korenevskiy Dist.	72.8	13.6	13.6	4.9	21.0	74.1	11.8	1.3	2.8	1.4	8.2	36.6	62.1
30 VII	Kremyannoe, Korenevskiy Dist.	67.6	22.3	10.1	4.2	5.8	90.8	41.9	8.4	7.8	4.6	8.6	169.6	240.9
31 VII	Lyubimovka, Korenevskiy Dist.	77.9	12.2	9.9	5.2	8.9	85.9	33.3	3.2	5.2	3.9	9.1	111.7	166.4
9 VIII	Blagodatnoe, Korenevskiy Dist.	74.1	9.8	16.1	2.4	7.3	90.3	30.5	2.4	8.2	1.8	7.2	112.9	163.0
10 VIII	Sheptukhovka, Korenevskiy Dist.	67.1	26.6	6.3	2.1	5.5	92.4	31.9	7.7	3.8	1.8	6.2	133.6	185.0
10 VIII	Murinovka, Korenevskiy Dist.	57.0	1.3	41.7	2.2	4.6	93.2	52.7	0.7	48.0	3.5	10.1	262.4	377.4
11 VIII	Vyshnie Dereven'ki L'govskiy Dist.	75.1	12.1	12.8	5.1	6.6	88.3	41.1	4.0	8.8	5.0	8.6	147.0	214.5
18 VIII	Kukuevka, Streletskiy Dist.	79.2	8.8	12.0	5.3	11.0	83.7	59.5	4.0	11.2	7.1	19.7	191.6	293.1
28 VIII	Storozhevoe, Bol'shoe-Soldatskiy Dist.	63.4	8.3	28.3	6.2	22.8	71.0	18.4	1.5	10.2	3.2	15.9	62.9	112.1
28 VIII	Balkatovo, Oboyanskiy Dist	28.2	7.7	64.1	1.8	10.6	87.6	19.2	3.2	54.5	2.1	17.3	181.8	278.1
30 VIII	Nemcha, Bol'she-Soldatskiy Dist.	63.4	23.3	13.3	1.9	3.6	94.5	39.3	8.8	10.2	2.1	5.3	178.2	243.9
3 IX	Levshenko, Bol'she-Soldatskiy Dist.	60.1	17.1	22.8	1.3	5.7	93.0	38.1	6.6	18.0	1.4	8.6	179.4	252.1
3 IX	3 km from Skorednoe Bol'she-Soldatskiy Dist.	55.0	15.8	29.2	1.9	2.9	95.2	23.0	4.0	15.2	1.4	2.9	121.4	167.9

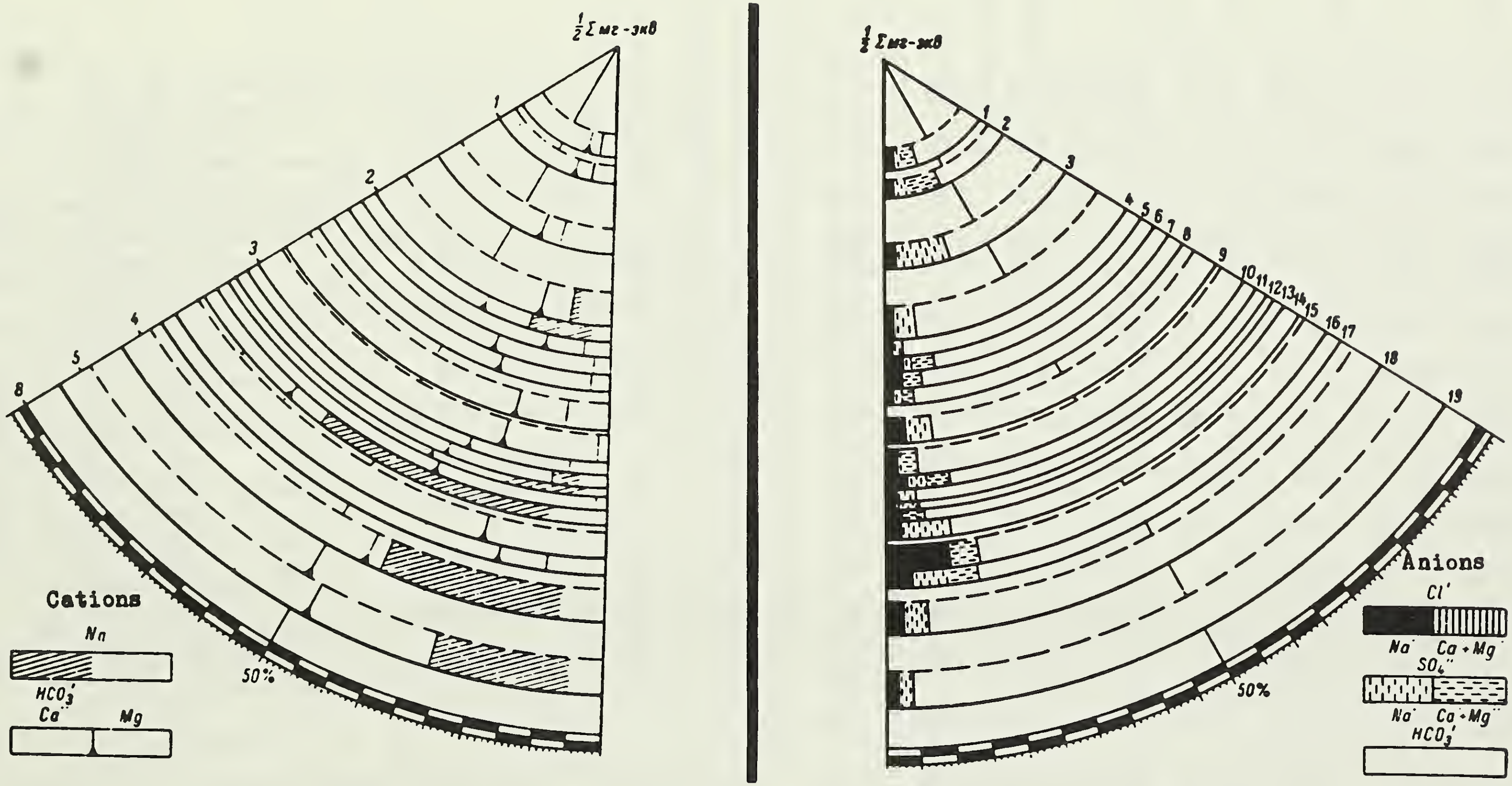

FIG. 3. Ion Composition of Pond Water in the Kursk & Orel Provinces in the Summer

1 - 3 km from Kremyannyy, Korenevskiy Dist., 7/29/1958; 2 - in Durovka, Korenevskiy Dist., 7/29/58; 3 - in Storozhevoe, Bol'she - Soldatskiy Dist., 8/28/58; 4 - in Blagodatnoe, Korenevskiy Dist., 8/9/58; 5 - 3 km from Skorednyy, Bol'she - Soldatskiy Dist., 9/3/58; 6- in Lyubimovka, Korenevskiy Dist., 7/31/58; 7 - in Al'shanskie, vyselki Orel Dist., 8/8/59; 8 - in Sheptukhovka, Korenevskiy Dist., 8/10/58; 9 - in Vyshnie dereven'ki L'govskiy Dist., 8/11/58; 10 - near Kroma, Kromskiy Dist., 8/8/59; 11 - in Kremyannoe, Korenevskiy Dist., 7/30/58; 12 - in Nemoha, Bol'she - Soldatskiy Dist., 8/30/58; 13 - in Levshenka, Bol'she - Soldatskiy Dist., 9/3/58; 14 - in Pervyy, voin Mtsenskiy Dist., 8/6/59; 15 - in Bashkatova, Oboyanskiy Dist., 8/28/58; 16 - near Malaya Kulikovka, Orel Dist., 8/7/59; 17 - in Kukuevka, Streletskiy Dist., 8/18/58; 18 - in Murinovka, Korenevskiy Dist., 8/10/58; 19 - in Durnovka, Ivaninskiy Dist., 7/3/57.

near Kremyannyy in the Korenevskiy District and in the Storozhevoe of the Bol'she Soldatskiy District serve as examples.

The increase in mineralization of pond water is connected with the increase in the HCO_3^- and Ca^{++} ion content which is due to the inflow of ground water. The prevalence of HCO_3^- ions among the anions is expressed more strongly than the prevalence of Ca^{++} ions in the cation composition.

The age of the pond does not affect the forming of ion composition and its mineralization. The ion composition and degree of mineralization of pond water are not subject to important changes in connection with the processes which take place within the water body of the reservoir. The products of erosion entering the reservoir are usually well leached and do not enrich the water with readily soluble mineral salts.

In addition to the ponds in the Kursk Province a number of reservoirs (Table 3) were investigated in the Orel Province. Their mineralization ranges within the same limits, and the water belongs in the bicarbonate class of the Ca^{++} group. The bicarbonate character is sharply expressed (82-93%). The content of Mg^{++} ions which among the cations occupy in all cases the second place after Ca^{++} is relatively high. No alkaline waters were found.

Thus, there are on the investigated territory ponds in which the water exchange takes place without participation of ground water. They maintain a weakly mineralized (less than 100 mg/lit.) water of the high-water period which in its ion composition reflects the peculiarities of the soils of the catchment, as for instance, the pond in the sanctuary, the one at Durovka and near Kremyannyy. These ponds are distinguished by a weakly expressed bicarbonate character and by a relatively high SO_4^{--} ion content.

TABLE 3

MINERALIZATION AND CHEMICAL COMPOSITION OF POND WATER IN THE OREL PROVINCE IN THE SUMMER

Date	Location of pond	Cations (% mg-equiv.)			Anions (% mg-equiv.)			Cations (mg/lit)			Anions (mg/lit)			Sum of ions mg/lit
		Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Cl^-	SO_4^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Cl^-	SO_4^{2-}	HCO_3^-	
1959 6 VIII	Pervyy Voin Mtsenk Dist.	62.2	34.7	3.1	3.1	4.3	92.6	62.2	13.9	2.5	3.6	6.7	185.5	277.4
7 VIII	Malaya Kulikovka Orel Dist.	75.1	24.9	0.0	12.2	5.7	82.1	84.5	11.2	0.0	16.0	10.1	184.9	306.7
8 VIII	Al'shanskie Vyselki Orel Dist.	63.2	30.8	6.0	5.1	5.1	89.8	45.1	8.8	3.5	4.2	5.8	128.1	195.5
8 VIII	Kroma, Kromskiy Dist.	74.3	22.1	3.6	1.6	5.6	92.8	68.9	8.1	2.8	1.8	8.2	172.1	261.9

The mineralization of ponds in the feeding of which ground water takes part does not reach high value and, on the average, does not exceed 400 mg/lit. Among the anions the HCO_3^- dominates and the pond water is distinguished by an expressed bicarbonate character. Although Ca^{++} ion is the leading one among the cations its prevalence is less strongly expressed. The difference in the leaching of soils is conducive to a relative increase in the Mg^{++} ion content in some reservoirs and to an increase in Na^+ ions and formation of sodium alkali water in others.

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Ya. K. K O V A L E V

TURBIDITY OF RIVERS AND ITS DISTRIBUTION IN THE CENTRAL CHERNOZEM PROVINCES

An analysis of factual data on turbidity and on its areal distribution is of great theoretical and practical importance.

The work of G.V.Lopatin (1939), B.V.Polyakov (1946), and G.I.Shamov (1954) established that the turbidity of a river characterizes to a certain extent the erosion processes in its basin.

It is true that the turbidity in the channel reflects quantitatively only that part of the eroded material which reaches the channel and is carried by the flow in suspension. The products of erosion which are retained in the different depressions on the way to the channel and also all the bed-load and dissolved sediment which sometimes constitute an important part of eroded material are not accounted for.

The turbidity of a river which depends on many factors is a part of the geographical landscape and is therefore subject to the general regularity of the areal distribution of landscape zones and can be mapped.

In mapping turbidity the areal or zoning method is usually employed which allows a considerable fluctuation in turbidity of different basins within the zone. For this reason it is not possible to interpolate turbidity within a zone.

G.V.Lopatin was the first (in 1937-1938) to undertake mapping of the average turbidity over the European part of the USSR; later (1957) improved maps were published. Lopatin presents a map of the average turbidity of the rivers of the Soviet Union which was constructed in 1953.

In accordance with G.V.Lopatin's map the territory which we investigated falls in three zones.

The zone with turbidity 20-50 g/m^3 includes the lower reaches of the Tsna and Miksha Rivers which extend into the Tambov Province where erosion processes are weaker because of the plain relief and sandy depressions. The 50-100 g/m^3 turbidity zone includes the greater part of the territory except for the Mid-Russian Highlands Region and of a small area in the southeast of the considered territory.

The headwaters of the Oka, Desna and Don Rivers lie in the 100-150 g/m turbidity zone, where the higher turbidity is due to the characteristics of the relief and to the geologic structure, to the lack of natural vegetation on the steppe slopes of the valleys, and to the high proportion of cultivation. This zone includes also a small area lying in the southeast of the Central Chernozem Provinces (CCP).

On G.I.Shamov's map published in 1954, four zones are shown in the CCP. A fifth zone with a turbidity of 250-500 g/m^3 includes the part of the Mid-Russian Highlands bounded: on the west by an almost straight line from the mouth of the Zusha River along the left side of the Oka River Basin to the Town of Kursk; on the south and east by a half circle passing approximately through the Town of Elets up to the administrative boundary; and on the north by a jagged line passing along the Zusha River.

Part of the right side of the Don Basin, the basin of the Voronezh River and a narrow strip south of Kursk are placed in the second zone with a turbidity of 25-50 g/m^3.

The third zone with a turbidity of 50-100 g/m^3 shown on the map as a narrow strip extending in the direction of the Cities of Tambov, Voronezh, and Suma includes the headwaters of the Tsna River which lie in the center of the Oka-Don Lowland, the lower reaches of the catchment of the Voronezh River, and the headwaters of the Oskol River on the right side of the Don.

The entire remaining part of the territory which includes river catchments with quite non-uniform physical-geographical characteristics is included in the fourth zone with a turbidity of 100-250 g/m^3.

From the abovesaid it is obvious that the distribution of average turbidity over the territory is not at all uniform. Four zones with strongly differing limits of turbidity had to be delineated in a relatively small area.

However, the boundaries of the zone shown in published maps of average turbidity do not sufficiently consider or reflect the local physical-geographical conditions of catchments and must therefore be improved.

The need to make the zone boundaries more precise is justified by the existence of additional data. During the last ten years the number of gaging stations at which observations were made of suspended sediment increased and the period of record was lengthened. In addition, during the same period the physical-geographical characteristics of the territory were studied in detail.

The data which we collected on suspended sediment in the rivers of the CCP and of the adjoining territory are shown in the table. The extrapolation of the record was made graphically. Values of normal water flow were taken from K.P.Voskresenskiy's paper, "Normals and Variability of Annual River Flow in the Soviet Union" published in 1962.

Almost at all points the observations are for the decade which is characterized by an average stream flow and therefore, by an average flow of suspended sediment, confirmed by the chronological graphs of fluctuations of average turbidity shown in Figure 1. In the wet year 1952 the turbidity was high at the majority of the stations. 1950 and especially 1954 were the dry years of the decade. This is also well reflected in these curves. Regrettably,

AVERAGE TURBIDITY OF RIVERS IN THE CENTRAL CHERNOZEM AND ADJOINING PROVINCES

River and point	F, km^2	Period of record	Years of record	For period of record: Q_{av} m^3/sec.	For period of record: $R_{av.}$ kg/sec.	For period of record: $P_{av.}$ g/m^3	Converted to long-term: Q_o m^3/sec.	Converted to long-term: R_o kg/sec.	Converted to long-term: P_o g/m^3
Don Basin									
Sosna - Belomestnaya	7650	1959—1960	2	39	15	385	36	14.5	403
Sosna - Elets	16300	1950—1960	11	73.8	47	637	76.5	48.5	634
Don - Zadonsk	31200	1960	1	169	66	391	—	—	—
Voronezh - Voronezh	21100	1951—1953	3	90.6	6.8	75	78.1	4.8	62
Khava - Il'inovka	426	1955—1960	6	1.42	0.382	269	1.24	0.296	242
Kalitva - Ol'khovatka	1250	1960	1	5.12	1.9	371	—	—	—
Vorona - Chutanovka	5560	1945—1947, 1949—1960	15	19.3	2.58	134	18.3	2.3	126
Karachan - Aleshki	565	1952—1953, 1955—1960	8	1.8	1.14	633	1.58	0.90	566
Buguluk - Kikvidze	3460	1953—1957	5	8.37	2.2	263	6.23	1.65	265
Khoper - Balashov	14300	1939, 1944, 1947, 1950—1952, 1954—1960	13	38.4	3.54	92	47.2	4.55	97
Khoper - Novokhopersk	34800	1940, 1949—1960	13	101.5	12.45	123	104.0	14.6	141
Oskol - Ninovka	6270	1956—1959	4	23.6	7.00	295	27.0	10.2	378
Oka Basin									
Oka - Orel	4890	1941, 1949—1952	5	23.8	8.88	373	20.6	7.4	359
Oka - Kaluga	54900	1935—1940, 1950—1960	17	271	39.1	144	296.0	44.4	150
Zusha - Mtsensk	6000	1950—1960	11	29.8	4.89	164	29.4	4.5	153
Upa - Orlovo	8400	1951—1960	10	43.3	4.78	111	43.7	5.0	114
Tsna - Knyashevo	13600	1943	1	30.8	0.47	18.0	—	—	—
Dnepr Basin									
Seym - Lebyazh'e	4870	1938—1939	2	14.1	1.25	89.0	—	—	—
Tuskar' - Kursk	2380	1938, 1945, 1948—1951, 1953, 1955—1960	13	10.0	1.76	176	10.7	1.8	168
Svapa - Gorod	3690	1950—1960	11	18.4	1.45	79.0	16.2	1.15	71.0
Seym - Ryl'sk	18100	1940, 1949—1960	13	77.4	2.1	27.0	76.0	1.92	25.0
Desna - Bryansk	12400	1938—1940, 1950—1959	13	75.1	2.43	32.0	76.9	2.34	31.0
Psel - Sumy	7770	1939, 1953—1954, 1956—1960	8	23.4	1.26	54.0	27.2	1.36	50
Sula - Lubny	14200	1938—1940, 1949—1960	15	26.6	0.45	17	37.0	0.67	18

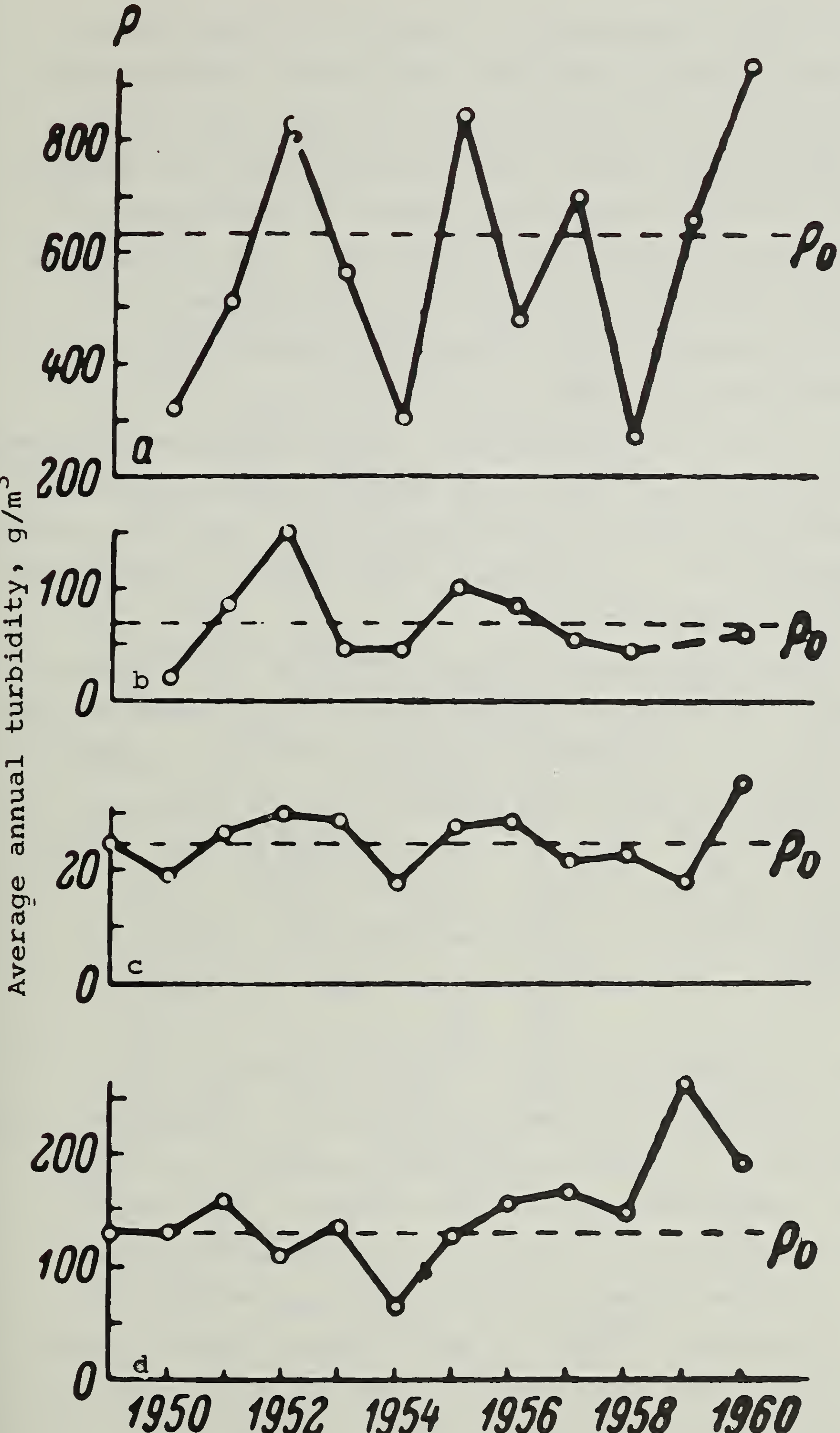

FIG. 1. Variations in Mean Annual Turbidity of Rivers in the Central Chernozem Provinces 1950-1960

a - Sosna Riv. at Elets; b - Svapa Riv. at Gorod; c - Seym Riv. at Ryl'sk; d - Vorona Riv. at Chutanovka.

the stations at which suspended sediment is observed are distributed non-uniformly over the territory. The western and eastern parts of the considered territory are well covered by observations, while the southern part is almost not covered at all which naturally makes it difficult to define the zone and to draw the boundaries. It is obvious that in this case one must, in defining the zones, lean on their physical-geographical characteristics taking into account the activities of Man.

In defining the zone we used as a basis data of sediment flow for the period up to 1960 (see table) and the papers of K.P.Voskresenskiy (1948); I.N.Ezhov (1957) and F.N.Mil'kov (1957, 1961) which cover quite fully the natural conditions of the investigated territory.

Figure 2 shows the map we constructed of the zones of average turbidity the descriptions of which are given below.

The territory of the CCP is divided into four zones with the following limits of turbidity: Zone A with a turbidity of 20-50 g/m^3, Zone B - 50-100 g/m^3; Zone C - 100-200 g/m^3 and Zone D - 200-500 g/m^3.

Zone D with a range of average turbidity of 200 to 500 g/m^3 lies within the boundaries of the Mid-Russian Highlands.

In accordance with the data on mean turbidity and taking into account the physical-geographical characteristics the eastern boundary of Zone D is drawn somewhat to the west of the Don approximately to the mouth of the right tributary, the River Snova, where it turns southwestward to the Kshen' River and then proceeds northwestward, and following the watershed divide of the Tuskar' River, makes a smooth bend along the left side of the Oka River northward. This includes the Oka River Basin without the headwaters of its left tributaries, the basin of the

FIG. 2 LONG TERM MEAN ANNUAL TURBIDITY OF RIVERS OF THE CENTRAL CHERNOZEM PROVINCES
Turbidity zones, g/m^3: A - 20-50; B - 50-100; C - 100-200: D - 200-500.

Bystraya Sosna, without the upper right tributaries - the Rivers Tim, Kshen' and Olym.

The turbidity of the Zusha River at Mtsensk is lower than that taken for Zone D which can obviously be explained by the prevalence here of karst phenomena. This area must therefore belong to Zone C.

The relief of the zone is an upland, the area is considerably dissected by a ravine-gully net, the density of which reaches 1.1 km/km^2. The greatest number of gullies is noted in the east of the zone.

In the Oka River Basin the watershed divides are narrow and rise 50-75 m above the river channels. The highest elevation above sea level is found in the basin of the Zusha River where it reaches 280-300 m. The slopes of the valleys of the rivers and of the gullies and ravine are relatively gentle and the presence of clay layers leads to the formation of landslides.

In the basin of the Sosna River the valleys of the rivers and of the ravines are narrow and deep with quite steep slopes. Flood plains are weakly developed, and locally are entirely lacking. The watershed divides are narrow.

The geological structure is characterized by the presence of devonian limestones with sandy clay layers. At the surface are loess-like clays and loams. Traces of karst phenomena in the form of dolinas, saucer lakes and ponors (swallow holes) in the bottoms of the ravines are often encountered. Only on the right side of the Sosna River in the basins of its tributaries - the Tim and Kshen' and Olym Rivers does the erosional dissection decrease and the relief becomes undulating. Many sinks are encountered on the watershed divides.

Forests and brush which protect the soil from erosion by snowmelt and rain waters are lacking. The typical steppe vegetation has almost disappeared, the steppes are cultivated.

Leached loam and southern clayey chernozems with spots of gray forest soils predominate. In the headwaters of the right tributaries of the Sosna River the soils are rich chernozems.

The annual precipitation is 550-600 mm. In the summer intense rains occur which cause high floods especially on small rivers.

A stable snow cover occurs every year, the average long-term water equivalent of the snow is 80-120 mm. Snow melting is rapid which causes high high-water in the rivers.

The presented information explains well the high turbidity in the rivers of Zone D.

Zone C with an average turbidity of 100-200 g/m^3 includes the eastern and southern parts of the CCP. The boundary of this zone passes along the watershed divides of the Vorona, Savala, Tokay and Osered' Rivers and thence from the mouth of the Bityug River northwesterly along the left side of the Don almost to the mouth of the Voronezh River whence it stretches out along a straight line westward and only south of the Town of Kursk it curves southward. Here lie the basins of the river which occupy the Kalach Highland and the western slopes of the Privolzhskaya Highland. On the right side of the Don there are included the basins of the Bogucharka, Chernaya Kalitva, Tikhaya Sosna, Potudan' and Oskol Rivers and the headwaters of the Severnyy Donets, of the Vorskla, Psel and the Seym.

Judging by the 1960 data only the Karachan River at Aleshki has a high turbidity which is explained by its small catchment area. And so does the Chernaya Kalitva River at Ol'khovatka.

The relief of the greater part of this zone is elevated and is of the ravine-gully type, the basin of the Vorona River lying on the western slopes of the Privolzhskaya Highland is highly dissected by valleys of

rivers and of ravines, the entrenchment of which ranges from 15-70 m. The ravine-gully net occupies more than 4% of the catchment area.

Present erosion is characterized by active gully heads and steep slopes. In addition to ravines which cut the slopes of the valleys there are also bottom ravines. The large gullies, the presence of sandy clay formations and other physical-geographical factors result in a high turbidity.

Within the Kalach Highlands the relief is of the ravine-gully type. Here ravines and gullies are now growing rapidly. The river valleys and dry ravines are 100-125 m deep. The highland is composed of chalk and tertiary formations.

As contrasted with these areas the catchments of the Savala, Elan' and Karachan Rivers have a predominantly plain relief. The rivers are weakly entrenched, the river valleys are well cultivated, the slopes are composed of loess-like loams.

The relief of the Chernaya Kalitva River basin is undulating, locally densely dissected by branching valleys of rivers and ravines. The slopes and the wide bottoms are covered with grass vegetation, there are forests closer to the ridges.

The relief in the basins of the Potudan' and Tikhaya Sosna Rivers is an elevated undulating ravine plain with wide and deep ravines and gullies. White chalk outcrops along the slopes of the valley. The valleys are well cultivated, the depth of entrenchment is 100-120 m. The flood plains are narrow and locally swampy. The soils are rich chernozem. The precipitation is 450-500 mm. Average water equivalent of snow is about 70 mm.

In the basins of the Oskol and of the Severnyy Donets the relief is a plain strongly dissected by valleys of rivers and ravines. Outcrops of writing chalk occur

frequently on the slopes. The territory is unforested and the divides are cultivated. The soils are represented by ordinary chernozems of varying depth.

Forest vegetation occurs in flood plains and in ravines. In the lower reaches of the Vorona River lies the famous old oak grove - Tellermanovskaya Roshcha. The steppe vegetation remains only on the slopes of the valleys, the greater part of the territory is cultivated.

In average years the precipitation is about 450 mm, in dry years it drops to 200 mm.

The average water equivalent of snow in the Vorona River Basin is 100-140 mm and on the Kalach Highland about 70 mm.

The rate of snow melting in the Spring is considerable.

Zone B with a turbidity of 50-100 g/m^3 extends in a half moon around Zone D. It includes the basin of the Voronezh River, the left and part of the right side of the Don, its right tributaries - the Veduga and Devitsa Rivers, the headwaters of the right tributaries of the Bol'shaya Sosna - the Olym, Kshen' and Tim Rivers, the basin of the Tuskar' River, and the headwater of the Svapa and of the left tributaries of the Oka River.

It should be noted that the left side of the Voronezh River with a plain relief, gentle slopes of the valley and a partially forested flood plain is, with respect to its natural conditions, more like Zone A, however, considering the turbidity at the City of Voronezh (62.0 g/m^3) we refrained from subdividing this basin.

The average turbidity of the Tuskar' and Khava Rivers which is higher than that of the zone is explained by the relief and by the sizes of the catchment. These areas are shown by dotted lines on the map.

The relief of the Don-Voronezh inter-river area is elevated and dissected by deep ravines and gullies. The right side of the Voronezh River is composed of limestone in the north and sand in the south. The left bank is gentle

and is composed of sand over the entire distance.

The relief of the basins of such rivers as the Snova, Veduga and Devitsa is of the ravine-gully type with an absolute elevation of about 230 m. This is the region of the eastern steep slopes of the Mid-Russian Highland. The slopes of the inter-river areas are gentle and are distinguished by dense and deep erosional dissection. The gullies are entrenched to a depth of 30-40 m, and have steep slopes and narrow watershed divides.

Ravines are highly developed, their development is aided by the considerable cultivation in the area, the dissection of the relief, and the presence of highly erodible sandy-loam formations.

Further to the west the territory of this zone includes the escarpment of the Mid-Russian Highlands which gradually passes into the Dnepr Lowland.

The relief in the headwaters of the Svapa River down to the City of Dmitriev - L'govskiy can be called elevated. The highest elevation reaches 275 m. The territory is dissected by a deep net of valleys and ravines, with depths of 75-100 m. A similar picture of the relief is observed also on the left side of the Oka River.

In the Voronezh River Basin chernozems rich in humus predominate. On the right side of the same river and further north there are gray forest soils and leached and podzolized chernozems.

The inter-river areas are cultivated.

In the region of the City of Lipetsk and north of the City of Voronezh there are relatively many forests. The annual precipitation is 500-600 mm.

Zone A with an average turbidity of 20-50 g/m^3 is represented by two areas lying in the northeastern and western parts of the investigated territory.

Within the northeastern part lie the basin of the Tsna, Bityug, Ikorts and Khvorostan' Rivers and of the

headwaters of the Matyra and of the Voronezh Rivers. On the west this zone includes a small area of the Desna catchment, the Seym with its tributaries below the City of Kursk and part of the catchment of the Psel River. On the basis of available data given in the table and of the physical-geographical characteristics represented by the plain relief and low dissection we reduced the limits of turbidity of this territory.

The relief in the basins of the Tsna and Bityug Rivers lying in the center of the Oksko-Don Lowland is that of a depressed plain weakly dissected, almost without ravines or gullies, and poorly drained. The watershed divides are wide with small slopes and with closed depressions in which sinks and saucers - "Osinovye Kusty" are encountered. The river valleys are wide with gentle terraced slopes filled with quaternary deposits. The flood plains are mostly covered with meadow vegetation and are sometimes swampy. There are many flood plains and oxbow lakes.

The parent rock is represented by sandy layers overlain by glacial moraine. Chernozem soils predominate but in the Tsna River Basin sandy-podzolized soils are also widespread.

The forest cover in the Tsna River Basin reached 17%. In the Bityug River Basin there are almost no forests except for the left bank Khrenovskiy pinewood and the mixed forest near the Village Anna. The watershed divides are cultivated. The average water equivalent of snow is about 100 mm.

The left side of the Seym River Basin and the headwaters of the basins of the Seym, Psel and Vorskla Rivers occupy the western slope of the Mid-Russian Highland and have a smooth relief; there are almost no ravines or gullies. There are three terraces on the left side of the Seym. The valleys are well cultivated; to the west the depth of their entrenchment decreases and the width increases. Podzolized and leached chernozems predominate.

There are also Ukrainian and typical rich chernozems. There are almost no forests, the entire territory is cultivated. Precipitation is 500-600 mm. Average water equivalent of snow is 60-100 mm.

The turbidity fluctuations in the rivers within each of the defined zones are similar in nature but differ between zones. The higher the limit of turbidity of the zone the greater is the amplitude of its fluctuations. This is clearly seen in Figure 1 in which are presented chronological graphs of fluctuations of average turbidity at points in different zones at which observations are available for the last decade. Thus for the Sosna River at Elets (Zone D) the amplitude of the fluctuations is equal to 657 g/m^3. For the Vorona River at Chutanovka (Zone C) it is 192 g/m^3. For the Sosna River at the Staryy Gorod (Zone B) - 127 g/m^3 and for the Seym River at Ryl'sk (Zone A) it is 18 g/m^3.

We also examined the relation of the average turbidity to the catchment area which is shown in Figures 3 and 4. In constructing this relationship the values in the table were used. The curves are drawn as lower envelopes. Most of the deviating points lie above them.

Because the few observations were made during different periods and were of different durations, individual points on the graphs scatter and the curves must be considered quite tentative.

The deviations of the points from the drawn curves for some of the stations can be explained. Thus, Point 4 for the Voronezh River at Voronezh City lies off the regression line for Zone B. This is explained on the one hand by the physical-geographical characteristics of the right side of the catchment which has steep slopes and by the character of the river above the observation point. Moreover, in its approach to the City of Voronezh the Voronezh River

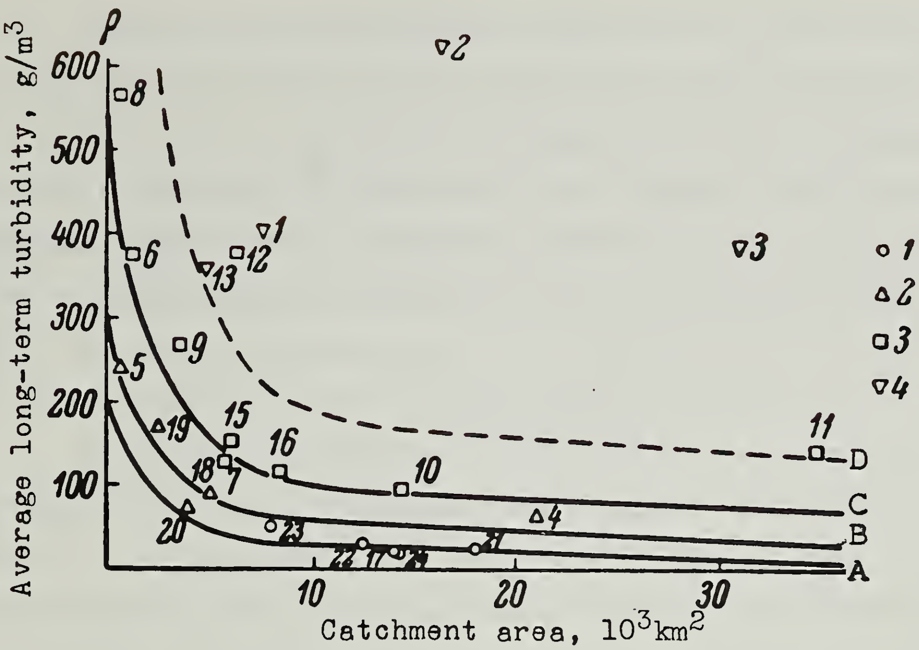

FIG. 3. Relation of Average Long-term Turbidity of Rivers of the Central Chernozem Provinces (by zones) to Catchment Area.

Turbidity zones (in g/m^3): A - 20 to 50; B - 50 to 100; C - 100 to 200; D - 200 to 500. Legend of turbidities: 1 - Zone A; 2 - B; 3 - C; 4 - D. Figures at points correspond to data in the table.

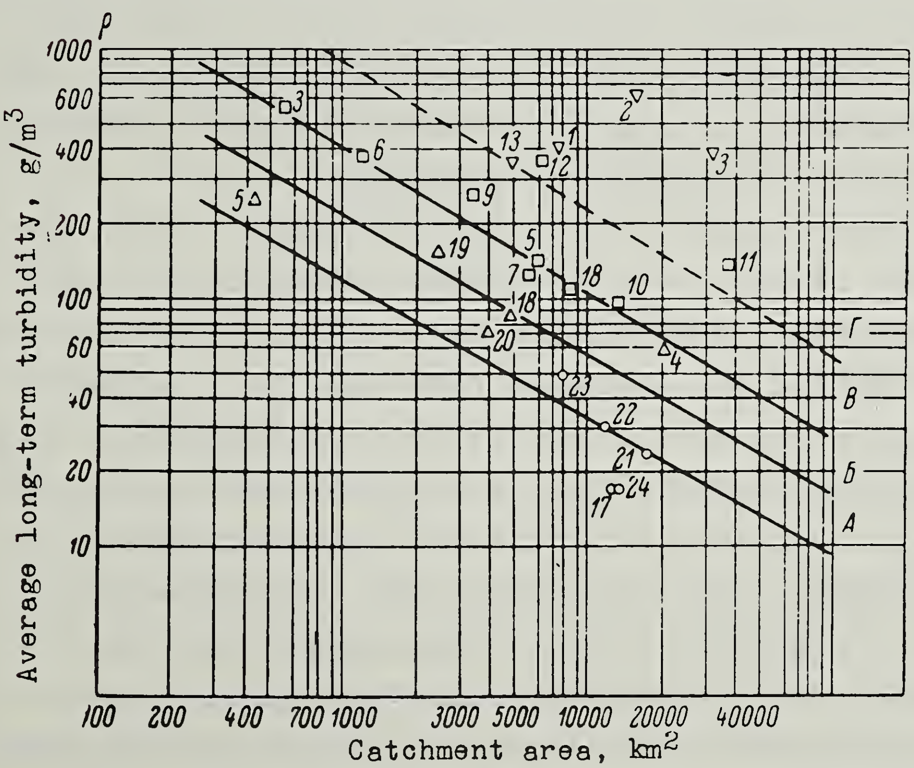

FIG. 4. Same as Fig. 3 Plotted Logarithmically

has a sandy left bank, a shallow channel with a sandy bottom and a considerable velocity which are conducive to a high turbidity at the closing section.

On the curve for Zone C the deviating points 11 and 12 are for the Khoper River at Novokhopersk. The high turbidity at this point can obviously be explained by the effect of the relief of the left side of the catchment lying on the slopes of the Privolshskaya Highland. The turbidity of the Oskol River at Ninovka (Point 12) was determined from data for only the last four years during which the turbidity was high.

The curve for Zone D has the greatest scatter of points, and is therefore drawn as a dashed line. Points 1 and 3 cannot be considered because they are based on observations for 1959-1960 only. The considerable deviation of Point 2 for the Sosna River at Elets is explained by the peculiar relief and by the nearly 100% cultivation.

In defining the zones of turbidity and establishing its relation to the catchment area we utilized observations on rivers with catchment areas greater than 500-600 km^2. Data for small catchments were not considered because the process of forming of turbidity in them differs strongly from those in large and medium catchments.

The map of the zones of average turbidity which we obtained for the rivers of the CCP was constructed with factual observational data taking into account the investigated physical-geographical characteristics, and can therefore in the first approximation characterize the examined regularity.

In conclusion we shall note that the construction of regional maps of average turbidity of rivers makes it possible to consider more accurately the available data and the natural characteristics of the region and to define in greater detail the zones and anomalous areas thus making it possible to determine with greater accuracy the average turbidity of uninvestigated rivers.

The turbidity determined from the map will make it possible to present more fully the distribution of erosion processes on the territory and to provide well-timed, suitable combinations of erosion control measures especially needed now when the plowed areas and planting of clean cultivated crops are rapidly increasing.

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V. Ya. FROLOV

WATER EROSION, THE FORMING OF SEDIMENT FLOW OF SMALL STREAMS IN THE CENTRAL CHERNOZEM PROVINCES AND MEASURES FOR PROTECTING RESERVOIRS FROM SILTING

The development of water erosion on catchments and the forming of sediment flow of certain small streams in the Central Chernozem Provinces (CCP) were treated separately in previous papers. This paper deals mainly with the computation of sediment flow from small catchments and recommendations for the protection of reservoirs from silting.

Soil erosion on catchments and the forming of the sediment flow of small streams depend, as is known, on physical-geographical conditions: relief, climate, soils, vegetation, and others. They are in large measures determined by the state of the surface of fields on the catchment and are connected with human economic activity.

Effect of Agricultural Development of the Catchment Areas on Soil Erosion

There is no unanimity among investigators on the question of the effect of different land use on the magnitude of water erosion. This is due primarily to the limited number of observations and to the different methods used in making them.

The magnitude of soil erosion on small catchments is determined mainly by measuring discharge and turbidity from runoff plots and in small streams on the investigated area (unit catchments), by measuring the volume of rills after the end of water runoff and also by comparing the thickness of the soil horizons along the slopes for the entire period from the beginning of cultivation. The available data obtained with these methods are given in Appendix 1.

The simplest method in use is considered that of S.S.Sobolev (1948). This method of observing total erosion from the volume of rills after the passage of water runoff found wide application among soil scientists. With this method there is no need for any water measuring devices. However, with such a method it isn't possible to reveal the dynamics of the erosion process or to compare the amount of erosion with the volume of runoff water. Moreover, in measuring the volumes of rills the considerable part of the product of water erosion which is deposited on the investigated area when the streamlines spread out has often not been taken into account with the result that the value of soil erosion determined by this method turns out to be, as a rule, too high.

The method of runoff plots is favored by hydrologists in the study of runoff water from different types of agricultural land. Runoff plots are usually installed near the watershed divide and on sloping parts of the catchment with surface slopes not exceeding 4^{o}. Their installation involves a number of technical difficulties. The relatively small size and their isolation from the inflow of water from adjoining areas naturally distort the nature of the studied phenomenon on the catchment, which makes this method similar to the one of determining erosion on monoliths.

Regrettably, observations of soil erosion from runoff plots are relatively few. Because of the large amount of work involved in taking and filtering a large number of water samples for turbidity, some of the runoff plot studies (Tregubov, 1961; Shamshin, 1961; Gonchar, 1962 and others) were often limited to the determination of soil erosion with S.S.Sobolev's method with its attendant errors. For the same reason the number of water samples taken for the determination of turbidity is often insufficient to fully represent the sediment runoff. Furthermore, the results of observations of sediment runoff from plots can be

affected by the type and design of the weirs which often lead to pondage in front of the overflow and unnatural settling out of sediment on the plot. Deserving mention in this respect are the runoff plots used by the Institute of Geography, Academy of Sciences, USSR (Nazarov and Razamikhin, 1958) on which the water collecting device consisted of asbestos cement pipes which eliminate ponding and the accumulation of sediment on the plot.

With respect to other methods of determination of the amount of water erosion it must be pointed out that they have not yet found wide application.

It is known that in the CCP most of the water and sediment runoff from the fields takes place in the Spring of the year. Yet the number of observations of soil erosion from plots in the Spring is extremely limited. Of the known works we shall note the investigations of A.M.Green (1961, 1963) and of P.S.Tregubov (1961). A.M.Green's investigations in the Kursk Province in the program of the Institute of Geography, Acad. of Sci., USSR 1958-1960 were concerned principally with the study of the effect of various types of agricultural land use on water runoff and erosion. The work of P.S.Tregubov at Kamennaya Steppe in the Voronezh Province in the program of the Dokuchaev Institute of Agriculture of the Central Chernozem Belt in 1958-1960 was devoted to a comparative study of methods of fall plowing on slopes.

Similar investigations of the effect of agricultural development of the territory on soil erosion were conducted also in the Trans-Volga (Nazarov, 1958; Kuznik, 1961), in the Pridesnyanskaya Highland of the Ukraine (Gonchar, 1962), in the central part of the European Territory of the country, the Tula Province (Shamshin, 1961), and in a number of other regions. A summary of the best known work in the USSR is given in Appendix 1. It is necessary here to note the

value of the results of I.A.Kuznik who conducted investigations in 1952-58 principally not on plots but on unit catchments, i.e., under natural conditions.

Because the method used in hydrology of expressing sediment flow in terms of turbidity (mg/lit., g/m^3) is in a number of cases inconvenient for determining soil erosion since the volume of water runoff is often unknown (for instance, when determining erosion from the volume of rills), we shall in what follows use also the depth of the eroded layer of the soil. Kuznik (1958) assumed that water erosion is proportional to the first power of the depth of water runoff and of the slope of the surface and expresses it thus

$$\mu = \alpha h I, \qquad (1)$$

where μ - the depth of eroded soil, microns; h - depth of water runoff, mm; I - surface slope ‰; α - erosion coefficient (a coefficient of proportionality). Hence,

$$\alpha = \frac{\mu}{hI} \qquad (2),$$

i.e., the erosion coefficient α represents the layer of eroded soil (the specific erosion) in microns, when the water runoff h = 1 mm and the slope of the surface I = 1‰. Using the values of specific erosion (Appendix 1) one can compare data from plots of different sizes with different surface slopes.

In the Spring when the main part (the cultivated) of the catchments in the CCP is bare (fall plowed), is in stubble, or is covered with small sprouts of winter crops, data on erosion from precisely such areas are of greatest interest. We shall first of all try to establish the ratios of erosion coefficients for the principal soils of the CCP.

The erodibility of the principal soils of the CCP can be determined best from the specific erosion on fall plowed land. It is known that the erodibility of soils is manifested when they are cultivated (plowed). A large amount of

data has been accumulated in hydrology which attests to the effect of fall plowing on the surface runoff of water. Data accumulated in different regions of the steppe and forest-steppe belts of the European USSR by: I.A.Kuznik (1952, 1954a), M.I.L'vovich (1954) and by G.V.Nazarov and N.V.Razumikhin (1958) for the Trans-Volga; by I.P.Sukharev (1955b), and P.S.Tregubov (1961) for the Voronezh Province; and by L.G.Onufrienko (1956), N.V.Pikush (1958) and A.S.Skorodumov (1955) and others for the Ukraine, prove the rather important hydrologic and agronomic effectiveness of fall plowing in reducing runoff in years of different wetness several-fold as compared with layland and stubble (Table 1). This effect of fall plowing is increasing toward the south.

On the other hand, with respect to erosion, the stirred-up fall plowed soil not bound by plant roots and having to a large extent lost its aggregation is most susceptible to water erosion (Appendix I). Fall plowing while conserving moisture on the fields is to a large degree conducive to erosion. It is therefore not accidental that in recent times individual agricultural specialists have expressed themselves increasingly more frequently against the use of fall plowing in erosion-prone regions with sufficient soil moisture (Kobez'kiy, 1946; Mikhaylenko, 1956; Sambur, 1956; Todorovskiy, 1956 and others). The question of the advisability of using fall plowing in the various districts of the CCP requires a thorough discussion. According to the data given in Appendix 1 the direction of fall plowing (up and down or across the slope) while strongly affecting the absolute value of erosion has a small influence on the value of specific erosion. On the average the specific erosion on fall plowed land turns out to be 0.05 mc for the deep chernozems which are most erosion resistant; for the ordinary chernozems it is 0.07 mc.

The data of A.S.Shamshin (1961) who conducted studies in the Tula Province on such soils cannot be used in the

TABLE 1

EFFECT OF FALL PLOWING ON SPRING RUNOFF IN DIFFERENT ZONES OF THE EUROPEAN USSR

Location	Period of Record	Soils	Runoff Coeff. Field, compacted soil	Runoff Coeff. Fall plowed	Ratio of Runoff Coeff.	Source of Information
Forest zone						
Moscow Agromet. Station	1922-30	Sod-podzolic	0.60	0.76	0.8	Nebol'sin & Nadeev (1937)
Valday Hydrologic Station	1951-52	Podzolic sandy loams	0.85	0.28	3.0	Uryvaev (1953)
Moscow Prov. Zvenigorod Dist.	1951-53	Sod-podzolic	0.77	0.84	0.9	Zhigalov (1955)
Forest-steppe zone						
Tula Province	1940-41	Gray forest-steppe	0.72	0.44	1.6	Shamshin (1961)
Pridesnyanskaya Runoff Station	1937	Podzolized chernozem	0.92	0.69	1.3	Skorodumov (1955)
Same	1949-53	Same	0.68	0.53	1.3	Onufrienko (1956)
Pridesnyanskiy base of the Ukr. Res. Inst. of Forestry & Agroforest Reclamation	1949-52	"	0.62	0.36	1.7	Gonchar (1962)
Boguslavskaya Runoff Sta. Inst. of Hydrology & Hydrotech. Acad. of Sci. Ukr. SSR	1951-52	Leached chernozem	0.88	0.49	1.8	Pikush (1958)
Kursk Sta. of the Inst. of Geography Acad. of Sci. USSR	1959-61	Deep chernozem	0.83	0.37	2.2	Green (1963)
Steppe Zone						
Dokuchaev Agric. Inst. of the Ts Ch P*	1952-53	Ordinary chernozem	0.74	0.51	1.4	Sukharev (1955 b)
Same	1958-60	Same	0.45	0.054	8.3	Tregubov (1961)
Timash forest reclamation base of the VNIALMI**	1954-57	"	0.71	0.15	4.7	Surmach (1959)
Tolstovka	1938-40	Dark chestnut	0.36	0.07	5.1	Kuznik (1952)
Engel's	1951-52	Same	0.50	0.10	5.0	Kuznik (1954a)
Saratov Prov. Ershov Dist.	1953-56	Chestnut	0.71	0.10	7.1	L'vovich (1954) Nazarov & Razumikhin (1958)

* Central Chernozem Belt

** All-Union Research Institute of Agroforest Reclamation

determination of the specific erosion on fall-plowed land with gray forested steppe soils. The results of these investigations of soil erosion with S.S.Sobolev's method proved by all evidence to be too high. Some idea of the erosion coefficient of gray forest-steppe soils of the Kursk Province is given by A.M.Green's data (Appendix 1). Thus, for instance, the specific erosion from a field after the potato harvest (gray forest-steppe soil) in the Spring of 1959 was 0.101 mc, while in the Spring of 1960 the specific erosion from winter crops on the same field was 0.039 mc, i.e., it exceeded the specific erosion from fall-plowed land with leached chernozem (0.081 and 0.022).

According to D.L.Armand's (1954) data obtained as a result of expeditionary work in the CCP (Table 2) erosion of gray forest-steppe soils is 1.5-2.0 times greater than that of chernozem soil. The erosion index of these soils was obtained in an indirect way - from their position on slopes of different steepness.

The data given in S.S.Sobolev's (1948) paper on the erodibility of the two compared soils confirm this difference. According to S.S.Sobolev's data the erodibility of gray forest soil is 3.5 times greater than that of calcareous chernozems.

It is known that there is a direct relationship between the physical-chemical indices of soils and their erodibility. The erosion indexes of gray forest and chernozem soils of the Novosil'skaya Agroforest Reclamation Experiment Station (Orel Province) obtained from the analysis of the data by P.I.Shavrygin (Table 3) which are given in A.S.Kozmenko's (1954) paper show that the erodibility of gray forest soil is 1.5-2.0 times higher than that of chernozems.

Therefore, the specific erosion from fall-plowed gray forest steppe soils of the CCP can be taken as 0.10.

TABLE 2

DEGREE OF EROSION OF GRAY-FOREST AND OF CHERNOZEM SOILS OF THE CENTRAL CHERNOZEM PROVINCES ON SLOPES OF DIFFERENT STEEPNESS (after D.L. Armand, 1954)

Degree of Erosion	Steepness of slope, degrees	
	Gray forest soils	Chernozem soils
Slightly eroded	< 2	< 3
Moderately eroded	1.5-3	2.5-4
Strongly eroded	2.5-4	3-5
Severely eroded	3-7	4-7
Completely eroded	> 7	> 7

TABLE 3

EROSION, INDEXES OF SOILS OF THE NOVOSIL'SKAYA AGROFOREST RECLAMATION STATION (AFTER P.I. SHAVRYGIN)

Erosion indexes	Degraded chernozem	Dark-gray forest loam	Light-gray forest loam
Dispersion[1]	0.63	0.75	0.92
Silica-sesquioxide ratio[2]	4.9	6.2	10.4
Dispersion ratio (after Middleton)[3]	14	17	25
Middleton's ratio[4]	1.9	1.7	1.6
Number of colloids[5]	32.1	26.9	21.0
Maximum hygroscopicity	9.64	8.09	6.31
Maximum molecular waterholding capacity	16.9	15.6	12.8
Erosion ratio[6]	7.3	9.8	15.2
Humus content	5.6	4.9	2.7
Nitrogen content	0.32	0.26	0.14

[1] Ratio of particles with d < 0.025 mm determined in the microaggregate composition without special preparation to the number of such particles determined in analysis with prior chemical preparation.

[2] Ratio of Al_2O_3+Fe_2O_3 determined in gross analysis (after Bennett) to sesquioxides.

[3] Ratio of silt and clay (sum of fractions d = 0.005-0.001 and d < 0.001 mm) found in a 1% suspension shaken 20 times, to the total number of such particles determined by the accepted international method.

[4] Ratio of colloids to the moisture equivalent.

[5] Ratio of maximum hygroscopicity to the coefficient 0.3 (after Robinson).

[6] Ratio of the moisture equivalent times the dispersion ratio to the number of colloids.

The effect of the vegetal cover on Spring erosion in the CCP can be evaluated from the value of the specific erosion from winter crops, stubble, fallow, and from perennial grasses and forests. We shall first of all note the relationship between Spring erosion and the density of the vegetal cover. According to the data in Appendix 1 the greatest erosion next to that from fall-plowed land occurs from winter crops. Thus, for instance, according to two years of observation by A.M.Green in the Kursk Province the specific erosion from winter crops even exceeded the similar values of erosion from fall-plowed land. According to somewhat longer observations of I.A.Kuznik in the Trans-Volga the specific erosion from winter crops proved to be 2.3 times less than from fall-plowed land. That soil erosion from winter crops is two or more times less than from fall-plowed land is attested to also by the experimental data of A.S.Shamshin (1961) in the Tula Province and of A.I.Gonchar (1962) in the Pridesnyanskaya Highland of the Ukraine. In A.M.Green's experiment a reverse relationship of erosion coefficients for winter crops and fall-plowed land was found. From all appearances the peculiar conditions of forming of sediment runoff from these fields exerted an influence here. In the Spring of 1959 and 1960 so-called "damping off" and a partial loss of winter plants occurred as a result of the formation everywhere in the CCP of a thick ice crust (Frolov, 1963). The compacted surface of the fields with sprouting winter crops lost a considerable part of its protective cover and became less erosion resistant than the fall-plowed land which was loosened in the fall. Also the results of the specific erosion for winter crops in A.M.Green's experiment, averaged for two plots, were obviously also affected by the different direction of the plant rows (up and down and across the slopes). The point is that with the direction of plant rows

of winter crops across the slopes additional obstacles to erosion are created (a decrease in the velocity of water runoff and the settling out of the sediment) while with the up and down direction, the velocity of surface runoff and correspondingly soil erosion are increased.

Regrettably, in determining erosion from winter crops the investigators do not, in most cases, indicate the direction of plant rows. Yet it is known that with the plant rows across the slope soil erosion is considerably less than when they run up and down the slope. In particular, according to A.M.Green's data which were analyzed at the zonal conference on combating erosion under the conditions of the CCP of the RSFSR in August, 1960 (Kursk Zonal Reclamation Experiment Station) of the Allunion Research Institute of Hydrotechnics and Reclamation, the erosion from winter crops in the Spring of 1959 with the plant rows up and down slope was 2.5 tons per hectar and with the plant rows across the slope only 0.37 tons per hectar, i.e., 6.8 times less. According to the data of N.K.Shikula (1962) erosion from chernozem soils in the Artemonovskiy District of the Donets Province in 1957-1960 with winter wheat planted across the slopes was reduced 3.4 fold, and according to observations of S.U.Kerimkhanov (1960) in the Klinsko-Dnitrievskaya Ridge District (Moscow Province) - 3.2 fold.

On the whole, the specific soil erosion from winter crops (rows up and down and across the slopes) is undoubtedly less than from fall-plowed land. Its magnitude depends on the density of the plants.

The same picture of erosion can be observed on layland and on fields in mixed grasses. Here during the first years after seeding when the vegetal cover is insufficiently developed, the specific soil erosion can be quite high. This is attested to in particular by the data

of G.V.Nazarov (1958) for the Trans-Volga (Appendix 1). In the experiments of this investigator were included fields with first and second year stands of perennial grasses. The specific erosion turned out to be higher than from other types of land use including fall-plowed land. On the basis of the obtained data, G.V.Nazarov reached the erroneous conclusion that in the Trans-Volga the greater erosion occurred from perennial grasses and stubble.

Actually, as follows from the data in Appendix 2, the specific erosion under the various climatic conditions of the USSR is least from land in stubble, layland and in perennial grasses. The greatest water runoff from these fields is explained primarily by the poor infiltration properties of the soil due to its compaction and also by the increased snow accumulation on such land. Moreover, the data in Appendix 1 show quite clearly that the effect of the soil types on erosion from these fields is considerably less than on that from fall-plowed land. Specific soil erosion from fields with the same vegetal cover fluctuates within comparatively narrow limits for the different soil types of the CCP.

On forested areas water erosion is practically zero (Green, 1960; Kuznik, 1961; and others).

The generalized data on water and sediment runoff from different agricultural land in relation to the principal soil types of the CCP presented in Table 4 show that water runoff from fall-plowed land is, in general, 1-1/2 - 2.0 times smaller than from land in winter crops. At the same time the specific erosion from fall-plowed soils is approximately 1-1/2 - 2.0 times higher. Thus water erosion from fall-plowed land and from winter crops which under conditions of the CCP according to our data (Frolov, 1962) occupy respectively 45-55 and 30-35% of the land is approximately the same. If one considered also that fall-plowing and winter crops

TABLE 4.

SPRING RUNOFF AND EROSION FROM THE PRINCIPAL SOILS OF THE CENTRAL CHERNOZEM PROVINCES WITH DIFFERENT LAND USE.

Land Use	Grey Forest Soils				Deep Chernozems				Ordinary Chernozems			
	Runoff Coeff.		Erosion Coeff.		Runoff Coeff.		Erosion Coeff.		Runoff Coeff.		Erosion Coeff.	
	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio
Fall plowed. . . .	0.44-0.69 (0.56)*	0.74	0.10	1.00	0.36-0.69 (0.52)	0.68	0.05	1.00	0.15-0.51 (0.33)	0.47	0.07	1.00
Winter crops . . .	0.53-0.90 (0.72)	0.95	0.05	0.50	0.54-0.80 (0.67)	0.88	0.025	0.50	0.40-0.71 (0.56)	0.80	0.03	0.43
Stubble.	(0.76)	1.00	0.02	0.20	0.52-0.90 (0.71)	1.00	0.005	0.10	0.50-0.62 (0.56)	0.80	0.01	0.14
Perennial grasses and long fallow. .	0.72-0.74 (0.73)	0.96	0.005	0.05	0.60-0.62 (0.61)	0.80	0.002	0.04	0.66-0.74 (0.70)	1.00	0.005	0.07
Forested	---	--	0	0	---	--	0	0	---	--	0	0

*Figures in parentheses are averaged values.

occupy the principal (up to 80-90%) part of the catchment areas it is obvious that the effect of other agricultural land on the total value of specific erosion (the erosion coefficient) will be almost negligible. As we shall see further, stubble, fallow and grasses protect the soil from water erosion principally by aiding the settling out of sediment on these areas. They can be a good means of water erosion control on steep slopes.

At the present time the composition of cropped areas in the CCP has undergone a number of changes. These changes, however, affect primarily the state of the land surface in the summer-fall period. On the one hand, there was an increase in clean cultivated crops (corn, sunflower, sugar beets) which require better tillage and protection against water erosion. On the other hand, clean fallow is everywhere being replaced by cropped fallow which tend to decrease water erosion in the summer because the crops on fallow (peas, cow peas, corn for sillage and others) bind the soil with their root system and save it from destruction.

The erosion hazard on various agricultural fields is different in the summer than in the Spring. It is known that in the CCP water runoff and erosion in the summer occurs only when a sufficient amount of rain occurs at one time - not less than 30-40 mm. According to I.P.Sukharev's (1955) observations in the Voronezh Province the runoff from a plot plowed across the slope was only 1.7 mm for a rainfall intensity of 2.5 mm/min. and a total amount of 243 mm. On plots plowed up and down; and on plots in stubble, winter wheat, first and second year grasses, on virgin land, and in a forest belt the water runoff was 22, 27.6, 16.2, 47, 21, and 6.2 mm respectively.

According to the data of G.P.Surmach (1962) who sprinkled monoliths of ordinary chernozem in the Kuybyshev Trans-Volga, the water erosion for a total rainfall of

58-82 mm with other conditions being equal depended on the degree of erosion (Table 5). According to the data given in this table the greatest specific erosion (1.88 microns) was noted on the clean cultivated (sunflower) field on moderately eroded soil. Harrowing of clean fallow across the slope on slightly eroded soils reduced the specific erosion as compared with up and down harrowing more than two-fold (from 0.64 to 0.30 microns).

Of great interest are the data published by I.A.Kuznik (1962) on water runoff and erosion with sprinkler irrigation on plots in the Dnepropetrovsk Province in 1937 and in the region of the Pridesnyanskaya Runoff Station in 1938. These data are given in Table 6. They show first of all that the greatest specific erosion for a total rainfall of from 30-120 mm was observed on clean fallow (0.10-0.61 microns). The specific erosion from fields in clean cultivated crops was also considerable (0.10-0.13 microns), but, on the whole, 5 times less than from clean fallow. Runoff from vegetal cover of different densities (stubble, layland, virgin land) turned out to be the same as from clean fallow. But erosion was small or practically non-existent.

That erosion in the summer is sharply reduced on fields covered with vegetation is shown also by the voluminous data of experiment stations in the USA. As an illustration we present in Table 7 the data taken from I.A.Kuznik (1962) on soil erosion at the Alabama Experiment Station which show that with a rainfall intensity of 3.3 mm/min. erosion from fields in vetch on different slopes (from 0 to 20%) was 10-50 times small than from clean fallow.

Therefore, the erosion hazard during the summer and fall period is greatest on clean fallow and on fields in row crops. At the present time, the increase in the area of row crops in the CCP can cause further development of water erosion unless appropriate erosion control measures are undertaken.

TABLE 5

RUNOFF AND EROSION FROM DIFFERENT FIELDS AND AGRICULTURAL LAND IN THE KUYBYSHEV TRANSVOLGA WITH SPRINKLER IRRIGATION (AFTER G.P. SURMACH 1962)

Land use	Degree of erosion	Slope, ‰	Precipitation mm	Runoff, mm	Runoff coefficient	Av. turbidity g/lit.	Erosion, mc	Erosion coefficient
Virgin land grazed	None	150	82	10	0.12	1.2	10	0.007
Perennial grasses second year stubble	"	40	80	25	0.31	10.4	217	0.22
Clean fallow cultivated on contour	Slight	45	78	23	0.30	15.8	308	0.30
Same, up and down		55	80	27	0.34	24.9	942	0.64
Sunflower	Moderate	55	58	20	0.34	49.4	2067	1.88

TABLE 6

RUNOFF AND EROSION FROM DIFFERENT FIELDS AND AGRICULTURAL LAND IN THE UKRAINE RESULTING FROM DIFFERENT AMOUNTS OF PRECIPITATION (APPLIED AS SPRINKLER IRRIGATION)

Land use	Surface slope,‰	Runoff,mm				Erosion, mc				Erosion coefficient			
		Total precipitation,mm											
		30	45	60	120	30	45	60	120	30	45	60	120
Dnepropetrovsk Province 1937													
Clean fallow .	158	1.3	1.3	23.6	—	107	25	2276	—	0.520	0.105	0.610	—
Corn	158	6.0	6.0	22.6	—	102	98	450	—	0.108	0.103	0.126	—
Oat stubble .	158	1.8	6.9	26.8	—	85	33	266	—	0.300	0.026	0.063	—
Layland . . .	158	0.0	0.3	11.2	—	0.0	0.0	16	—	0.0	0.0	0.009	—
Virgin land .	158	0.0	0.09	0.25	—	0.0	0.0	0.0	—	0.0	0.0	0.0	—
Pridesnyanskiy Base 1938													
Clean fallow on virgin land	249	0.36	0.0	19.9	97.0	12	0.0	671	3764	0.134	0.0	0.135	0.156
Oat stubble	158	10.0	—	31.8	90.6	38	—	113	619	0.024	—	0.022	0.043
Virgin land	249	4.9	1.1	30.1	86.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 7

EROSION FROM DIFFERENT AGRICULTURAL FIELDS OF THE ALABAMA EXPERIMENT STATION (USA) ON SLOPES OF DIFFERENT STEEPNESS FOR A RAIN INTENSITY OF 3.3 mm/min.

Field	Erosion (T/ha) for slopes of:				
	0°	5°	10°	15°	20°
Freshly plowed	0.61	2.12	2.32	9.52	29.30
Field free of vegetation	0.46	1.09	1.52	6.73	9.26
Vetch	0.06	0.08	0.09	0.57	0.61

As shown by the observations of S.L.Shchekleyn (1937,1938) in the Kirov Province and of A.S.Shamshin (1961)in the Tula Province, such measures which sharply reduce erosion from clean cultivated fields include the most elementary agro-technical practices for row crops. Thus, for instance, according to A.S.Shamshin 0.67 tons/ha of soil was washed off in the summer of 1940 from a clean fallow field in the Tula Province. From a potato field planted and cultivated across the slope the erosion was only 0.062 tons/ha, i.e., 10.8 times less. It is also obvious that other row crops (corn, sugar beets) which have a large root system and a large canopy will also protect the soil from erosion in the summer if planted by the check row method. The soil is first cultivated up and down and then across the slope.

It is known, however, (Frolov, 1961b) that although the large northwestern part of the CCP lies within the intense rainfall region the rainfall intensity and frequency of intense rain there are not very high. Considering that the universal replacement in the CCP of clean fallow by cropped fallow and also the correct (first up and down and then across the slope) cultivation of fields in row crops can lead to a reduction of erosion during the summer-fall period; the fear of further intensification of erosion is obviously unwarranted.

Therefore, the forming of sediment flow of small

streams in the CCP is determined principally by the composition and pattern of agricultural land in the Spring of the year which, as stated above, remained unchanged in recent times. The values of specific soil erosion on different fields for the Spring period shown in Table 4 can be utilized in determining sediment flow.

Regime and Amount of Sediment Flow in Small Streams of the Central Chernozem Provinces

It was pointed out in our previous papers (Frolov, 1961a, 1961b, 1963) that the principal part of the sediment flow in small streams of the CCP is formed during the period of Spring high water by erosion from slopes of adjoining areas.

We studied the regime of Spring flow of water and of sediments in greatest detail on the catchment of the Uspenskoe Reservoirs in the Kursk Province (Frolov, 1963). It was then noted that the distinguishing feature of the regime of Spring water-and sediment flows of two ravines - Merech'e and Raychik - is their rate and diurnal variations. In the diurnal fluctuations of turbidity and of water discharge, there was noted a certain lag (by 1-2 hours) of the peak of water discharge behind the peak of turbidity.

The Spring water-and sediment flow during the entire period of high water in the mentioned ravines was also not uniform over the three year period of observation (1959-1961). The principal part of water-and sediment flows (50-80%) passed through the ravines at the initial stage of the high water, in 2-3 days at the middle and less frequently at the beginning of the second snow melting period (the period of formation of thawed patches).

Because of the short period of the study of sediment flow on the catchment of the Uspenskoe Reservoir it is interesting to compare these values with the regime and the amount of sediment flow of some other small streams with a longer period of record. For this purpose we

utilized the data on water-and sediment flow of some small streams with catchment areas less than 500-600 km^2 published in the "Hydrologic Yearbook", and also the "Observational Data of the Nizhnedevitskaya Runoff Station of the Administration of the Hydrometeorological Service of the CCP."

Measurements of water-and sediment runoff from small catchments of the Nizhnedevitskaya Runoff Station have been made since 1948. The data of these measurements for the period of 1948-1955 were published in two volumes, those for 1956-1960 we obtained from the Administration of the Hydrometeorological Service of the CCP. It is necessary to point out that in the "Materialy..." (1955, 1961) are given only data on turbidity and water discharge, but no results of the computed sediment flow. A longer period of turbidity record is available for two ravines: Barsuk (1949-1960) and Medvezhiy (1950-1960). We computed the sediment flow of these and other ravines from daily graphs of variations in turbidity constructed by extrapolation taking into account the more frequent measurements of turbidity of small streams of the Kursk Province. In the construction of the chronological graphs of diurnal variations of turbidity their peaks were determined by extrapolating the rises and recessions (Fig. 1). Sediment flow was determined by multiplying the hourly water discharges by the corresponding turbidity and by subsequent summation.

Data on the sediment flow of small streams in the CCP are contained in Table 8. The long-term monthly distribution of water-and sediment flow (in %) of the Karachan at Aleshki (Voronezh Province), of the Kur River at Kazatskaya (Kursk Province) and also of the Barsuk and Medvezhiy Ravines is given in Table 9. The data in Table 9 show that the forming of the sediment flow of small streams in the CCP takes place principally in the Spring (at the end of March or

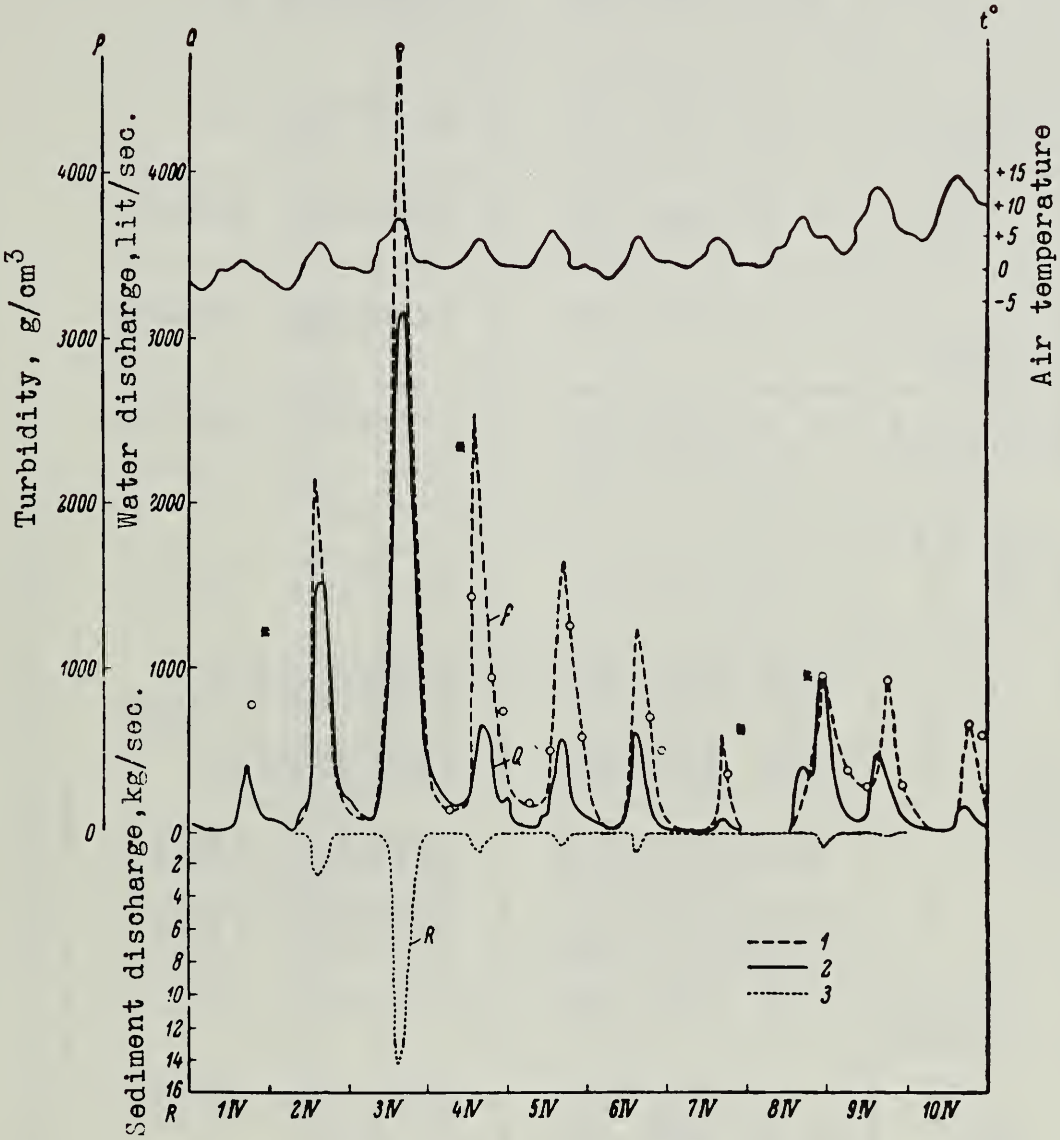

FIG. 1. FLUCTUATION OF TURBIDITY (ρ) AND OF DISCHARGES OF WATER (Q) AND OF SEDIMENT (R) OF THE BARSUK RAVINE IN THE SPRING OF 1959.

1 - turbidity; 2 - water discharge; 3 - sediment discharge.

Table 8

MEAN ANNUAL WATER AND SUSPENDED SEDIMENT FLOW OF SMALL STREAMS IN THE CENTRAL CHERNOZEM PROVINCES

River, point [1]	Catchment area, F, km^2	Avg. slope of catchment, I, ‰	Period of record		Years of record		Averages for yrs. of sediment flow		Averages for years of water flow			Erosion coefficient α
			Water	Sediment	Water	Sediment	Water runoff h, mm	Sediment runoff, μ, mc	Water runoff h, mm	Sediment runoff, μ, mc	Turbidity, ρ, g/m^3	
Karachan - Aleshki	565	27	1952—1953, 1956—1959	1952—1953, 1956—1959	6	6	96	51	96	51	638	0.020
Khava - Il'inovka	426	27	1951—1954, 1956—1959	1956—1959	8	4	98	21	96	20	250	0.0077
Kosta - Glazovo	139	46	1950—1959	1956—1959	10	4	217	12	170	9	64	0.0012
Bobrovnik - Pisarev . . .	99.6	44	1952—1957	1952—1957	6	6	131	25	131	25	229	0.0043
Orlitsa - Bol'shoy Rog . .	96.0	72	1950, 1953—1959	1953—1959	8	7	132	9	131	8	75	0.00085
Kur - Kazatskaya	66.0	56	1949—1958	1952—1958	10	7	103	73	100	72	863	0.013
Kleshnya - Rakitno	58.0	24	1951—1954, 1956—1958	1953—1954, 1956, 1958	7	4	92	11	110	14	152	0.0053
Borshchen' - Borshchen Reservoir	48.0	75	1956—1958	1956—1958	3	3	85	146	74 [2]	96	1560	0.017
Rzhava rav.-Uspenskoe Reservoir	33.2	68	1959—1961	1959—1961	3	3	58	67	75 [2]	131	2100	0.026
Merech'e rav.-Alekseevskiy	8.69	68	1959—1961	1959—1961	3	3	58	55	75 [2]	71	1140	0.014
Raychik-P. Lukashevka . .	6.49	75	1959—1961	1959—1961	3	3	56	158	75 [2]	212	3390	0.038
Barsuk rav. - gag. sta. .	10.7	62	1949—1960	1949—1960	12	12	62	90	62	90	1740	0.023
Medvezhiy rav. - gag sta.	2.55	46	1950—1960	1950—1960	11	11	58	81	58	81	1680	0.030
Ivkin rav. - gag. sta. . .	0.55	78	1949—1960	1949—1955	12	7	44	202	50	285	7110	0.073
Churakov rav. - gag. sta.	1.56	78	1950, 1952—1957	1950, 1952—1953, 1955	7	4	92	1150	92	1150	15300	0.160
Tat'yanin rav. - gag. sta.	0.18	220	1950—1960	1950—1952	11	3	125	172	113	150	1590	0.0060
Dolgiy rav. - gag. sta.	2.57	87	1949—1960	1951—1952	12	2	23	49	22	—	—	(0.024)
Barskiy rav. - gag. sta. .	3.16	64	1952—1960	1952	9	1	89	148	82	—	—	(0.026)
M. Repnyy rav. - gag. sta	0.23	25	1955—1960	1959	6	1	94	31	91	—	—	(0.013)
Malyutka rav. - gag. st	0.06	79	1954—1960	1960	7	1	130	199	91	—	—	(0.019)

1 See Appendix 2 and Fig. 5 for location of streams.

2 Water runoff was determined by K.P. Voskresenskiy's method (1951).

TABLE 9

INTRAANNUAL DISTRIBUTION OF WATER (W) AND SEDIMENT (R) FLOWS OF SMALL STREAMS OF THE CENTRAL CHERNOZEM PROVINCES

River, point	Catchment area km^2	Period of record	Item	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	Hydrologic season: Winter	Spring	Summer	Fall
Medvezhiy rav.- gaging sta. . .	2.55	1950–1960	W	1.9	3.9	36.8	48.9	0.7	0.7	0.5	0.7	0.3	0.5	0.2	4.9	100.0	10.7	85.7	2.6	1.0
			R	0.2	0.4	33.7	59.6	0.3	0.2	0.1	0.1	0.0	0.1	0.0	5.3	100.0	5.9	93.3	0.7	0.1
Barsuk rav.- gaging sta. . .	10.7	1949–1960	W	3.5	8.8	49.3	33.9	0.0	0.3	0.3	0.0	0.0	0.0	0.0	3.9	100.0	16.2	83.2	0.6	0.0
			R	0.2	0.5	56.8	41.0	0.0	0.5	0.6	0.0	0.0	0.0	0.0	0.4	100.0	1.1	97.8	1.1	0.0
Kur riv.- Kazatskaya . .	66.0	1952–1958	W	2.6	4.3	25.1	34.0	4.3	5.8	3.4	5.4	1.5	3.5	4.3	5.8	100.0	12.7	59.1	18.9	9.3
			R	1.7	4.8	23.3	36.6	4.0	10.0	3.1	6.2	1.2	3.0	2.4	3.7	100.0	10.2	59.9	23.3	6.6
Karachan riv.- Aleshki	565.0	1952–1953, 1956–1959	W	0.2	2.6	5.4	87.9	2.5	0.2	0.2	0.2	0.0	0.3	0.2	0.3	100.0	3.1	93.3	3.1	0.5
			R	0.0	0.3	0.4	98.1	1.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	100.0	0.3	98.5	1.1	0.1

beginning of April). 85% of the entire annual water flow and 95% of the sediment flow in the intermittent streams (ravines and gullies) of the CCP occur during the Spring of the year (March-April). In small perennial streams (Kur River) the Spring water- and sediment flows are about 60% of the annual. The quite substantial percentage of the winter water flow of both intermittent and perennial small streams (10-15% of the annual) is the result of frequent winter thaws and floods. However, the sediment flow for this period of the year does not exceed 10-15% of the annual even in small rivers. The sediment flow of intermittent streams during the summer-fall and winter periods of the year is quite small (not greater than 2-4% of the annual) or is entirely nonexistent. The somewhat high (up to 20% and greater) sediment flow of perennial streams during the summer is due mainly to the erosion of their channels.

It is especially interesting to compare data of concurrent measurements on small streams of the Kursk Province and of the Nizhnedevitskaya Runoff Station for 1958-1960.

The meteorological conditions in the area where we did our work (Kursk Province) and at the Nizhnedevitskaya Runoff Station were about the same for these years. According to the data of the Nizhnedevitskaya Runoff Station the Spring of 1958 was late. Air temperature passed the zero mark during the period of 4-6 April (6-8 days later than normal). Snow melting was quite rapid. The Spring flow was less than normal and lasted from 27 March to 1 April.

In the Spring of 1959 the melting of snow was slow, the weather was overcast and cool with night frosts. The flow in the ravines lasted from 23-30 March. On the whole, the Spring of 1959 was relatively dry.

In the Spring of 1960 the high water developed in the third 10-day period of March. The air temperature passed the 0° mark on 28 March. Snow melting was quite rapid. In spite of winter thaws the snow accumulation which increased toward Spring resulted in a high high-water peak. The Spring was wet.

As seen in Figure 1, the water-and sediment flows of the ravines on the Nizhnedevitskaya Runoff Station were distinguished by their diurnal variations. As in the small streams of the Kursk Province the fluctuations of water- and sediment discharges in the ravines of the runoff stations were rapid. In spite of the cloudy or radiation weather the rise in the water level in the ravines began every day at 8-10 o'clock and continued to 14-16 o'clock. The turbidity increased simultaneously with the water flow. The turbidity peak was ahead of that of the water discharge. The recession of the discharge and turbidity was also rapid. In other words, the regime of the water-and sediment flows of small streams of the Kursk and Voronezh Provinces was, in general, the same.

The Spring water-and sediment flows in small streams for 1958-1960 are compared in Table 10.

Therefore, the regime of water and sediment flow of small streams which we studied in detail under conditions of the Kursk Province (Frolov, 1963) is obviously typical for the majority of similar streams in the CCP. This was, in the main, our basis for computing the sediment flow of small streams of the Nizhnedevitskaya Runoff Station from a relatively small amount of data on daily turbidity (see above). Consequently, the principal conclusions as to the nature of the regime of water and sediment flows drawn from the measurements in small streams of the Kursk and Voronezh Provinces can be applied also to other regions of the CCP.

T a b l e 10

SPRING-WATER AND SEDIMENT RUNOFF FROM SMALL CATCHMENTS IN THE KURSK AND VORONEZH PROVINCES FOR 1958-1960

Item	1958			1959				1960			
	Borshchen' creek	Barsuk rav.	Medvezhiy rav.	Merech'e rav.	Raychik rav.	Barsuk rav.	Medvezhiy rav.	Merech'e rav.	Raychik rav.	Barsuk rav.	Medvezhiy rav.
Catchment area, km^2	48.0	10.7	2.55	8.69	6.49	10.7	2.55	8.69	6.49	10.7	2.55
Weighted average slope of the catchment, %.	75.2	62.0	46.0	68.2	75.2	62.0	46.0	68.2	75.2	62.0	46.0
Total water supply, mm	96.0	88.9	265.5	65.0	67.0	100.0	175.1	156.0	159.0	140.8	153.3
Same in % of long-term average	91.4	83.9	165.9	61.9	63.8	94.3	109.4	148.6	151.4	132.8	95.8
Beginning of runoff, date . . .	—	4 IV	5 IV	21 III	20 III	24 III	25 III	22 III	24 III	22 III	23 III
Ending of runoff, date	—	15 IV	16 IV	15 IV	31 III	14 IV	30 IV	23 IV	17 IV	17 IV	28 IV
Duration of runoff, days	—	12	12	26	12	22	37	33	25	27	37
Water runoff, mm	54.0	15.2	34.4	33.0	26.0	38.4	46.2	115.0	118.0	124.3	106.3
Same in % of long-term average	81.8	29.8	67.4	50.0	39.4	75.3	90.6	174.2	178.8	243.7	208.4
Coefficient of runoff	0.56	0.17	0.13	0.51	0.39	0.38	0.26	0.69	0.74	0.88	0.69
Max. rate of water runoff, /sec/ha (date)	—	4.0 / 6 IV	1.2 / 7 IV	3.8 / 26 III	1.7 / 26 III	2.9 / 3 IV	2.4 / 8 IV	8.4 / 30 III	6.2 / 31 III	9.6 / 30 III	11.7 / 30 III
Sediment runoff, mc	75.0	20.2	15.4	66.0	174.0	34.9	50.4	80.0	220.0	292.3	83.2
Max. rate of sediment runoff, g/sec/ha (date) . . .	—	12.2 / 6 IV	2.7 / 12 IV	15.0 / 26 III	42.0 / 24 III	13.2 / 3 IV	8.8 / 8 IV	13.0 / 30 III	34.0 / 31 III	48.9 / 30 III	17.7 / 30 III
Average turbidity, g/m^3	1670	1590	538	2400	8030	1090	1310	835	2240	2820	940
Erosion coefficient	0.018	0.021	0.010	0.029	0.089	0.015	0.024	0.010	0.025	0.038	0.017

R e m a r k s. 1. The long-term mean of total water supply for the area in which the Borshchen Creek and the Merech'e and Raychik Ravines are located is taken as 105 mm according to V.D.Komarov's (1959) data; for the catchments of the Barsuk and Medvezhiy Ravines it was determined from observations for 1949-1960 and is equal to 106 and 160 mm respectively. 2. The normal Spring water runoff for the catchments of the Borshchen' Creek and the Merech'e and Raychik Ravines was taken as 66 mm according to K.P.Voskresenskiy (1956); for the catchments of the Barsuk and the Medvezhiy Ravines the average Spring water runoff for the period of observation (1949-1960) turned out to be equal 51 mm. 3. The volume-weight of the eroded soil was taken to be 1.2 T/m^3.

As indicated above, the period of record of suspended sediment flow of small streams in the CCP is quite limited. For this reason the possibility of determining long-term mean annual sediment flow is of great interest. It is known that graphical relationships between mean annual sediment discharges and water discharges R=f(Q) are often used in determining the mean long-term flow of suspended sediment of large streams.

I.A.Kuznik (1958) in determining the normal sediment flow for the Trans-Volga rivers utilized the graphical relationship between the depth of erosion μ and the depth of spring water runoff h. In the majority of cases this relationship $\mu=f(h)$ was expressed by a straight line through the origin of the coordinates or less frequently by the equation of the type

$$\mu = ah - b, \tag{3}$$

where a - tangent of the angle of the straight line; b - the intercept on the ordinate. As a result of a statistical analysis of data on water-and sediment flow for two ravines with the longest period of record, Barsuk and Medvezhiy (Table 11) we obtained values of coefficients of variation of water-and sediment flow which prove to be equal to $C_{v_h} = 0.68$, $C_{v_\mu} = 1.01$ for the Barsuk Ravine and $C_{v_h} = 0.44$, $C_{v_\mu} = 0.48$ for the Medvezhiy Ravine.

The relationship $k_\mu = f\ (k_h)$ constructed for the above mentioned streams is represented by straight lines with an average deviation of $\pm$20-30%. Therefore, the graphical relationship $\mu = f\ (h)$ can with a known error be used for the determination of the mean long-term sediment flow of small streams as well as of river sediment flow. With such relationships for a number of small streams in the CCP it was possible to extend the period of record somewhat and to determine the average sediment flow for a longer period (Table 8).

Table 11

WATER AND SEDIMENT RUNOFF OF THE BARSUK (1949-1960) AND THE MEDVEZHIY (1950-1960) RAVINES

	Barsuk rav.				Medvezhiy rav.			
	Water runoff h, MM	Sediment runoff μ, MK	Module coefficient*		Water runoff h, MM	Sediment runoff μ, MK	Module coefficient *	
			$k_h = \frac{h}{h_0}$	$k_\mu = \frac{\mu}{\mu_0}$			$k_h = \frac{h}{h_0}$	$k_\mu = \frac{\mu}{\mu_0}$
1949 . .	15	5.3	0.24	0.06				
1950 . .	16	5.7	0.26	0.06	19	33	0.33	0.41
1951 . .	123	156	1.99	1.73	64	80	1.10	0.99
1952 . .	52	112	0.84	1.24	65	119	1.12	1.48
1953 . .	87	171	1.40	1.90	66	118	1.14	1.46
1954 . .	37	9.0	0.60	0.10	33	48	0.57	0.59
1955 . .	111	152	1.79	1.68	76	108	1.31	1.34
1956 . .	43	10.5	0.69	0.12	56	145	0.97	1.79
1957 . .	68	114	1.10	1.26	46	74	0.79	0.92
1958 . .	17	20.6	0.27	0.23	47	24	0.81	0.30
1959 . .	42	35.1	0.68	0.39	48	51	0.83	0.63
1960 . .	134	293	2.16	3.24	118	88	2.04	1.09
Sum	745	1084.2			638	888		
Average . .	62	90.3			58	80.7		

*Ratio of measured value to the long-term mean.

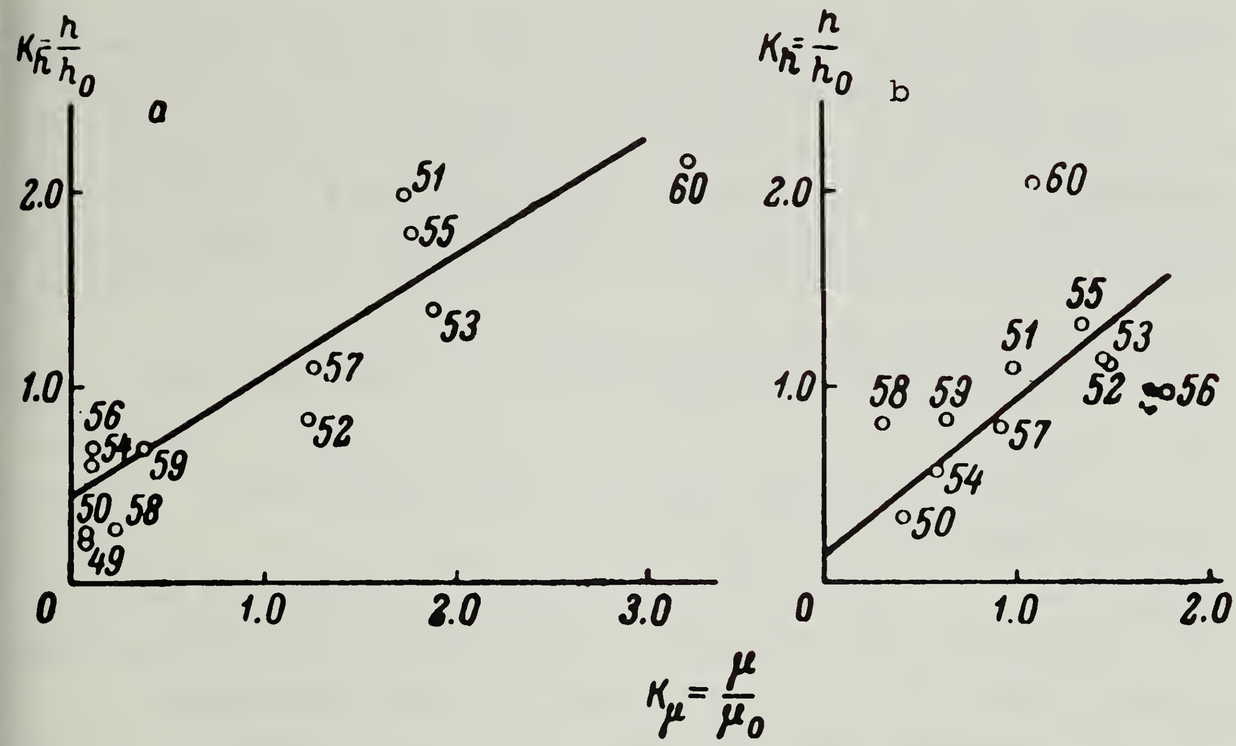

FIG. 2. Relationship between Runoff Coefficients of Sediment (K_μ) and of Water (K_h) of the Barsuk and Medvezhiy Ravines for 1940-1960.

a - Barsuk Ravine; b - Medvezhiy Ravine. Numbers at circles indicates years (dates) of the measurements.

According to the values in Table 8 the average long-term annual sediment flow of small streams of the CCP does, in most cases, not exceed 100-200 microns, i.e., 1.0-2.0 m^3/ha or 1.2-2.4 tons/ha (with a volume-weight of the eroded soil $\gamma = 1.2$ т/м^3). The sharp increase in sediment flow of the smallest individual streams with catchment areas less than 2-3 km^2 (the Ivkin, Churakov and other Ravines) is due principally to gully erosion.

In general, the sediment flow of small streams in the CCP corresponds to the value of erosion from the principal parts of the catchments obtained from runoff plot data (Appendix 1) and also agrees with the performed computations.

According to our calculations made with the data of the soil erosion survey of the Uspenskoe Reservoir catchment (Frolov, 1962) the average value of erosion in the areas near the drainage net was 0.3 m for the entire time since

the catchment was first plowed (about 100 years). Considering that erosion takes place primarily on the slopes of southern exposure the total area of which is 1.58 km^2 and assuming a volume-weight of the soil of γ 1.2 т/м^3 we find that the erosion from the given area is about 15-20 tons/ha/year:

$$\frac{1.58 \cdot 10^6 m^2 \cdot 0.3m \cdot 1.2\ T/m^3}{100\ yrs. \cdot 315\ ha} = 18\ T/ha\ per\ year.$$

This amounts to 5-6 thousand tons for the entire area near the drainage net (3.16 km^2).

Keeping in mind that about 75-80% of the total sediment flow comes from the area near the drainage net (Kozmenko,1954) we find that from the entire catchment of the Uspenskoe Reservoir 6-7 thousand tons of soil or 1.2-1.5 tons/ha (for a catchment of 48.0 km^2) is eroded on the average per year.

According to A.M.Pankov's (1937) investigation in the Rovenskiy District of the Voronezh Province, the erosion from the upper and middle part of the slopes was 10 tons/ha and from the part near the drainage net 100-200 tons/ha per year. G.P.Surmach (1961) calculated the total erosion for 350-400 years since the virgin land was plowed up. The average turned out to be 4.4 m^3/ha/yr. for the Novosilskiy District of the Orel Province and 4.7 m^3/ha/yr. for the Ostrogozhskiy District of the Voronezh Province. The mentioned author considers that for the CCP these values can be reduced to 1 m^3/ha/yr. because with the introduction of deep late-fall plowing and with a higher level of agriculture the water runoff was reduced by 25-30%.

Thus the mean annual value of sediment runoff from small catchments obtained from measurements in small streams represents the average depth of soil eroded from the surface of the catchment. It can likewise be obtained from data of specific erosion when data on land use on the catchment are available.

A number of local factors which in different combinations make up the elements of the natural landscape can exert an important influence on the forming of sediment runoff from small catchments. A comparison of the sediment flow of small streams of the CCP with many of these factors individually (catchment area, depth of the erosion base, density of the ravine-gully net, extent of cultivation on the catchment, and others) shows in many cases the lack of a satisfactory direct relationship between them. The closest relationship was noted only between the sediment runoff μ and the erosion-geomorphological coefficient α_{e-g} (Fig. 3) which as known (Frolov, 1961a,1961) is an overall water erosion characteristic of a catchment. The relationship between the sediment runoff and the erosion-geomorphological coefficient like the relationship between water-and sediment discharge is expressed by a straight line. Less clearly but also by a straight line is expressed the relationship between sediment runoff μ and the weighted average slope of the surface of the catchment I (Fig. 4). Thus the sediment runoff from small catchments can be expressed by Equation (1).

As was shown in our previous paper (Frolov, 1963) the sediment runoff of the majority of small catchments in the CCP is formed principally by products of sheet erosion. The part of gully erosion in the forming of the sediment flow is considerably smaller.

It is known that in the computations of channel deformations use can be made of a number of formulas of bedload discharge S which is related to the hydraulic characteristics of the channel and to the granulometric composition of the sediment. Having made a number of assumptions I.A.Kuznik (1958) performed an analysis for four ravines typical of the Povolzh'e with predominantly gully erosion using one of the simplified formulas of the type $S=bQi_{chann.}$ and obtained the analytical relationship:

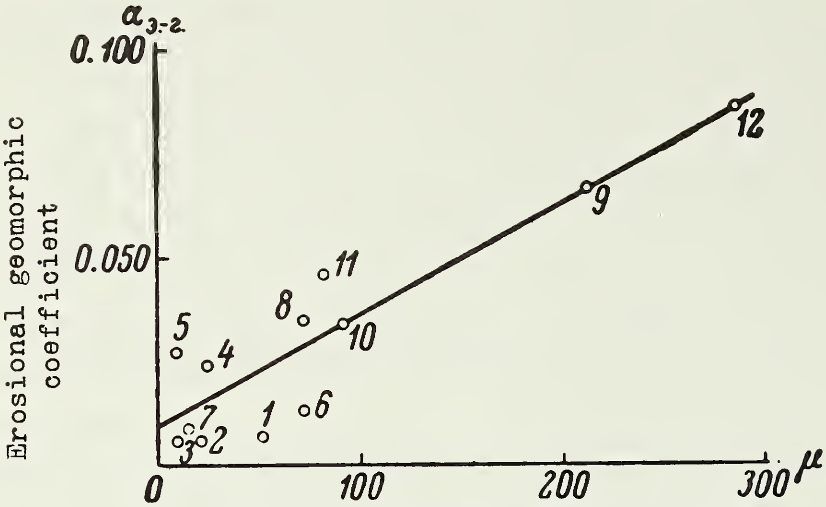

FIG. 3. Relation of Sediment Flow of Small Streams of the Central Chernozem Provinces (expressed in terms of depth of sediment runoff μ) to the erosional-geomorphological coefficient (α_{e-g}).

Numbers of circles indicate points of measurement as listed in App. 2.

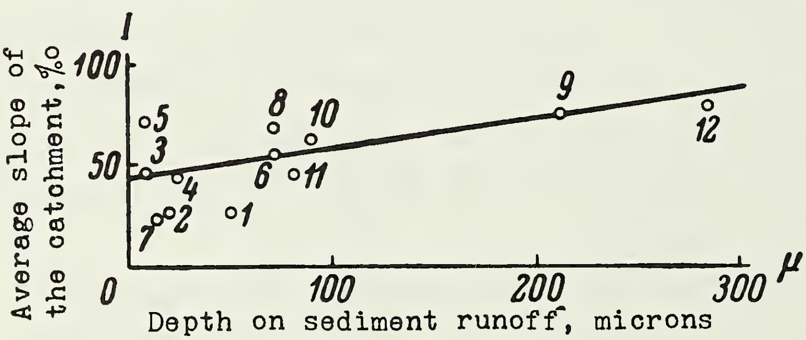

FIG. 4. Relation of Sediment Flow of Small Streams of the Central Chernozem Provinces (expressed in terms of depth of sediment runoff μ) to the average weighted slope of the surface of the catchments (I).

Numbers of circles indicate points of measurement as listed in App. 2.

$$\mu_{chann.} = \beta (q - 0.4)\, i_{chann.} \qquad (4)$$

where $\mu_{chann.}$ - the channel erosion in microns, applied to the entire area of the catchment; $i_{chann.}$ - average slope of the channel of the main ravine, ‰; q - rate of water runoff lit/sec km^2; 0.4 - a constant, corresponding to the maximum non-eroding velocity of the stream; and β - coefficient of channel erosion which, depending on channel stability varies from 0.5 to 4.5.

We do not have much data on the sediment flow of small streams of the CCP generally and especially of streams with absolute prevalence of gully erosion. Nevertheless, the calculations which we made for two ravines (Frolov, 1963) showed that the gully erosion of the Raychik Ravine computed from the difference $R_{meas.} - R_{sheet}$ did not exceed in individual years 20-40% of the measured sediment runoff, while for the Merech'e Ravine it turned out to be negative. It was also noted that in the latter case the settling out of sediment on the slopes exerted a strong influence.

A similar difference in the sediment runoff from small catchments was found on the ravines of the Nizhnedevitskaya Runoff Station. As follows from the data in Table 8 the mean annual depth of sediment runoff μ for the catchment as a whole was 81 microns for the Medvezhiy Ravine while that from only a small part of it (catchment of the Ivkin Ravine) was 285 mc, i.e., 3.5 times greater. It is obvious that in forming the sediment flow of the Ivkin Ravine the greatest part is played by gullying. It is also indisputable that in the other (forested) parts of the catchment of the Medvezhiy Ravine the phenomenon of settling out of sediment is developed to an incomparably greater extent. Sediment runoff from catchments in which there is gully erosion and deposition is, as known, (Frolov, 1963) sufficiently accurately determined by the sediment measured at the gaging station of the main ravine or by the

value of sheet erosion because the amount of sediment deposited on the slopes as a result of settling out is partially or fully compensated by the sediment from the gully head erosion which passes through the gaging section.

That the amount of sediment flow of small streams of the CCP is close to that of sheet erosion is attested to also by the results of measurements (see above). Therefore, the value of sediment runoff from small catchments in the CCP can be computed with Formula (1).

Returning to the data in Table 11 we shall point out also the difference in the amount and in the fluctuations of the sediment flow of the Barsuk and Medvezhiy Ravines. On the whole, the mean annual sediment runoff from the catchment of the Barsuk Ravine for a 12-year period was 90.3 and that for an 11-year period on the Medvezhiy Ravine was 80.7 mc. The coefficient of variation of the mean annual sediment runoff from these catchments for the same periods were 1.01 and 0.48 respectively. These differences in the sediment runoff are explained principally by the erosional-geomorphological characteristics of the catchments, information on which is given in Table 12. Of no small importance here is also the difference in the forest cover of these catchments (0 and 41% respectively). The more uniformly occurring processes of water erosion on the catchment of the Medvezhiy Ravine is to a large extent explained by the larger forest cover on its territory.

In talking about the forest cover of small catchments in the CCP and of the effect of afforested land on the formation of sediment runoff it is necessary to add that in the CCP the so-called "bayrachnye" forests which grow in the gully ravine net are most prevalent. Therefore, the condition of the principal part of the catchment on which the forming of sediment runoff principally occurs is determined not so much by the extent of its forest cover

Table 12

EROSION-GEOMORPHIC CHARACTERISTICS OF CATCHMENTS OF SMALL STREAMS OF THE CENTRAL CHERNOZEM PROVINCES

River, point	Catchment area, F, km^2	Depth of erosion base H, m	Length of the ravine-gulley net L, km	Ravine-gulley density n, km/km^2	Length of gulleys L', km	Gulley density n', km/km^2	Average slope of catchment, I, ‰	Average length of flow lines, km	Extent cultivated a, %	Forested %	Erosion-geomorphic coefficient $= \frac{H(n+n')a}{\sqrt[4]{F+1}}$
Karachan - Aleshki	565	60.9	384	0.68	—	—	27	0.74	80	0.8	0.0068
Khava - Il'inovka	426	52.8	290	0.68	—	—	27	0.72	75	1.2	0.0059
Kosta - Glazovo	139	38.5	122	0.88	—	—	46	0.57	55	14.0	0.0056
Bobrovnik - Pisarev	99.6	68.8	137	1.38	—	—	44	0.36	80	1.0	0.024
Orlitsa - Bol'shoy Rog	96.0	78.3	140	1.46	—	—	72	0.34	75	4.8	0.027
Kur - Kazatskaya	66.0	88.7	70.5	1.07	—	—	56	0.47	40	24.0	0.013
Kleshnya - Rakitno	58.0	57.0	38.0	0.66	—	—	24	0.71	65	2.6	0.0088
Borshchen' - Borshchen Reservoir	48.0	85.7	64.1	1.37	9.2	0.19	75	0.38	78	1.0	0.040
Rzhava rav.-Uspenskoe Reservoir	33.2	79.4	44.3	1.33	5.9	0.18	68	0.38	79	3.9	0.039
Merech'e rav.-Alekseevskiy	8.69	57.7	10.8	1.24	0.80	0.09	68	0.40	80	6.9	0.035
Raychik-P. Lukashevka	6.49	70.4	9.20	1.42	3.60	0.55	75	0.35	80	10.2	0.067
Barsuk rav. - gag. sta.	10.7	87.0	8.00	0.88	—	—	62	0.67	80	0.0	0.034
Medvezhiy rav. - gag. sta.	2.55	71.2	3.00	1.12	0.98	0.38	46	0.43	59	41.0	0.046
Ivkin rav. - gag. sta.	0.55	54.4	0.94	1.71	0.54	0.98	78	0.29	65	35.0	0.086
Churakov rav. - gag. sta.	1.56	65.5	2.40	1.54	2.40	1.54	78	0.32	61	0.0	0.098
Tat'yanin rav. - gag. sta.	0.18	56.5	0.72	4.00	0.60	3.33	220	0.12	11	0.0	0.044
Dolgiy rav. - gag. sta.	2.57	75.2	2.60	1.01	0.40	0.16	87	0.49	49	44.0	0.031
Barskiy rav. - gag. sta.	3.16	85.0	3.40	1.08	1.60	0.51	64	0.46	68	12.0	0.064
M. Repnyy rav. - gag. sta.	0.23	27.2	0.25	1.09	0.00	0.00	25	0.46	100	0.0	0.028
Malyutka rav. - gag. sta.	0.06	30.0	0.20	3.33	0.00	0.00	79	0.15	100	0.0	0.099

as by the extent of cultivation. The erosion resistance of forest land (Table 4) is incomparably greater than that of virgin land and of layland. It is, however, sufficiently well known that the unplowed (virgin) surface of the catchment like a forest stand serves as a dependable erosion-preventing cover. On this subject P.A.Kostychev (1886) wrote: "I traveled thousands of versts (verst = 1.07 km) over areas of unplowed chernozem and no where could I find in spite of my special bias not only obvious erosion and washing but even its slightest signs."

Therefore, in determining the water erosion characteristics of catchments we considered basically not the extent of the forest cover but the extent of cultivation on the catchment.

The effects of different conditions on the forming of the sediment flow of the Barsuk and Medvezhiy Ravines can be manifested by the values of the deviations of the points on the regression lines $K\mu = f(K_h)$ and also by the tangent of the angles of the straight lines (Fig. 2).

On the $K\mu = f(K_h)$ graph for the Barsuk Ravine the deviations of the points from the straight line is quite considerable but is more or less uniform. On the similar graph for the Medvezhiy Ravine, three points deviate greatly from the straight line (1956, 1958 and 1961). This is explained by the peculiar conditions of forming of the Spring sediment flow in these years.

According to the data of the Nizhnedevitskaya Runoff Station 1956 was, on the whole, an average year with respect to the flow with a comparatively high but extended Spring high water. There was little snow in the 1955/56 winter, however, because of the considerable forest cover the water equivalent of the snow on the catchment of the Medvezhiy Ravine exceeded that on the catchment of the Barsuk Ravine (177 mm as against 154 mm). As a result,

the depth of spring runoff waters of the Medvezhiy Ravine was high (56.1 mm). The considerable increase in the sediment flow of this ravine was due to the intensive gully erosion.

The winter of 1957/58 was distinguished by unstable weather. Protracted thaws were followed by snow storms. This led to an even greater non-uniformity of distribution of snow in the catchment than in 1956. Due to the accumulation in the forested areas the water supply in the snow before the beginning of the Spring high-water reached 96 mm. During the Spring snow melting copious rains occurred. The depth of runoff for the high-water period was 34.4 mm. Due to the infiltration of the spring water and the settling out of sediment on the forested areas the sediment runoff was relatively small.

In the Spring of 1960 like in the previous years large supplies of water were contained in the snow on the catchment of the Medvezhiy Ravine (123 mm). However, unlike in previous years this year the snow was lying more or less uniformly on a deeply frozen soil (up to 70 cm). The Spring melting of the snow at the end of March was rapid. On 30 March there was a rain of thunderstorm type. Surface water runoff occurred on a frozen soil. In spite of the high value of the water runoff (106.3 mm) erosion was insignificant.

And so, the forming of sediment flow of small streams in the CCP is determined not only by the water erosion characteristics of their catchments but also by the peculiar weather conditions of individual years which frequently lead to a considerable deviation of the sediment flow from the long-term mean. As was indicated above, the forming of the sediment flow of small streams depends principally on three factors: water runoff h, average weighted slope of the surface of the catchment I, and the

erosion coefficient α which, as we shall see later, is determined by a number of water erosion characteristics. The determination of the erosion coefficients in the computation of sediment runoff from small catchments usually presents the most difficult problem.

Methods of Computing Sediment Runoff from Small Catchments in the Central Chernozem Province

A quantitative estimate of the products of water erosion entering into reservoirs is possible by direct measurements in the ravine gully net or by computations from empirical relationships. Here it must be noted that the knowledge of sediment flow of small streams is so limited both in the USSR and abroad that the available data on sediment flow cannot be extended to other areas. They are of interest principally in checking the computations.

In planning and operating reservoirs the calculations of sediment inflow are, as a rule, based on field observations of turbidity of larger streams (rivers), and also of silting of reservoirs using various correction coefficients. Methods of estimating turbidity of small streams from data of sediment flows of large and medium rivers were worked out by a number of investigators (Polyakov, 1946; Voskresenskiy, 1951,1956; Lopatin, 1952, 1958; Lisitzyna,1960; Prytkova, 1960; and others).

Some authors (Myalkovskiy and Drozd, 1947; Mikhalchenkov, 1949; Sorokin, 1960; and others) obtained regional empirical relationships for the determination of turbidity at small streams from data on silting of ponds and reservoirs.

It is known that differences between the sediment runoff from large and small catchments are determined by the different physical-geographical conditions of these catchments and also by the sizes of their areas. With an increase in area of the catchment conditions are created

for more frequent redeposition of products of water erosion along the path of their movement into the principal channel; the turbidity of small streams ρ_{ℓ} as a rule exceeding the turbidity of larger watercourses ρ_s.

The relationship between turbidity of large and small streams can be determined by the equation:

$$\rho_s = \psi \rho_{\ell}, \tag{5}$$

where ψ - a coefficient for converting the turbidity of large rivers to that of small streams.

The conversion coefficient ψ can in the first approximation be determined taking into account the peculiarities of the natural conditions of catchments of large and small streams. The empirical relationships of B.V.Polyakov (1946) and of G.V.Lopatin (1952) for determining the turbidity of small streams take into account the effect of a number of physical-geographical conditions of small and large catchments on water erosion but do not account for such an important factor as the size of their areas.

More simplified methods of converting the turbidity of medium and large rivers to that of small streams with catchment areas less than 200-1000 km^2 were proposed by K.P.Voskresenskiy (1961, 1956), by G.V.Lopatin (1958), by K.N.Lisitsyna (1960), M.Ya.Prytkova (1960), and by I.N.Sorokin and L.V.Yakovleva (1961). These methods of determining the turbidity of small streams by means of conversion coefficients obtained from data of silting of ponds and reservoirs are even more approximate in nature because in this case in addition to neglecting the size of the catchment the effects on water erosion of a number of other no less important factors (the ravine-gully net density, the extent of cultivation, soil and climatic and other conditions) are not taken into account.

The use of empirical relationships for the determination of turbidity of small streams obtained for different regions

of the USSR from data of silting of reservoirs, of the type

$$\rho_s = AI^m, \qquad (6)$$

(where ρ_s - turbidity of small streams, I - longitudinal slope of the stream, m - an exponent)is quite complicated because it is often difficult to determine the value of the coefficient A. A number of investigators used this coefficient to account for the effect of the greatest variety of factors beginning with the nature of the soil and ending with water flow regulation.

In the absence of data on water erosion on catchments, I.A.Kuznik's (1948) method worked out for Povolzh'e conditions and somewhat transformed by us (Frolov, 1961a, 1961b) was used as a basis in the computation of the sediment flow of small streams in the CCP.

According to I.A.Kuznik:

$$\mu_{total} = \mu_{sheet} + \mu_{chann.} = \alpha hI + \beta(q - 0.4)\, i_{chann.} \qquad (7)$$

where μ is the depth of soil washed off the surface of the catchment, microns, α - coefficient of sheet erosion; h - depth of water runoff, mm; I and $i_{chann.}$ - the slopes of the surface of the catchment and of the channel of the main ravine, ‰; β - coefficient of channel erosion; q - the rate of water runoff, lit/sec/km^2; and 0.4 - a constant corresponding to the maximum (non-eroding) stream velocity.

According to I.A.Kuznik (1961) the coefficient of sheet erosion α is determined as a mean weighted value, depending on soil conditions and land use on the catchment, from data on specific erosion given in Table 13.

TABLE 13

SPECIFIC EROSION IN RELATION TO SOILS AND LAND USE (AFTER I.A. KUZNIK, 1958)

Land use	Ordinary chernozem	Southern sandy chernozems	Dark chestnut
Fall plowed-Cont.cultiv.	0.090	0.125	0.300
Sod and plowed sod	0.027	0.035	0.053
Winter crops-Cont.cultiv.	0.030	0.030	0.050
Long fallow and seeded perennial grasses	0.004	0.005	0.008
Forest	0.003	--	--

I.A.Kuznik (1958b) recommends that the mean weighted slopes of the surface of the catchment be determined by the formula

$$I_{av.} = \frac{\sum i \cdot f}{F}, \qquad (8)$$

where i and f are slopes and areas of individual parts of the catchment; F - the area of the entire catchment; i being determined from a map of slopes prepared by I.A.Kuznik for the Povolzh'e region.

Under conditions of the CCP where the processes of overgrowing of slopes of ravines are strongly developed (Frolov, 1961b, 1963) the principal quantity of sediment in the ravine-gully net is formed by sheet erosion. Here even for individual ravines the value of gully erosion (according to I.A.Kuznik - channel) in the total balance of sediment from a trenched (gully) catchment constitutes only an insignificant part.

Therefore, neglecting the value $u_{chann.}$ in Formula (7) we have

$$\mu_{tot.} = \mu_{sheet} = \alpha h I. \qquad (9)$$

Multiplying the left and right sides of Equation (9) by the area of the catchment F km^2 we obtain:

$$R_{s,v} = \alpha W I, \qquad (10)$$

where $R_{s,v}$ - volume of sediment flow, m^3; W - volume of water flow, $10^3 m^3$; I - slope of the surface of the catchment, ‰; and α - the erosion coefficient, or specific erosion.

To convert sediment flow from volume to weight units it is necessary to multiply the right side of Equation (1) by the volume-weight of the soil eroded from the surface of the catchment which for the CCP condition is according to P.M.Bereshkovskiy's (1962) data on the average $\gamma = 1.2$ т/м³. Therefore, in weight units the sediment runoff from small catchments in the CCP will be equal to

$$R_{s,w} = 1.2 \alpha W I, \qquad (11)$$

where $R_{s,w}$ is the weight of sediment, tons.

Here it must be noted that the structure of Formulas (10) and (11) obtained for the computation of sediment runoff of small catchments in the CCP as well as in Povolzh'e is determined by the existence of a straight line relationship between the sediment runoff and the principal factors which determine it: water runoff, mean weighted slope of the surface of the catchment, and the erosion coefficient (see above).

To obtain the value of mean annual turbidity of a stream it is necessary to divide the right and left sides of Equation (11) by $W \cdot 10^3 m^3$.
Then we have the well known expression

$$\rho_s = 1.2 \alpha \cdot I \cdot 10^3 \qquad (12)$$

where ρ_s - mean annual turbidity, g/m^3.

The value of the erosion coefficient (specific erosion) can be obtained from data on erosion from different agricultural fields and land. According to our analysis the values of specific erosion α from different types of agriculture fields with the principal soil types of the CCP are represented by the data given in Table 4. Knowing the soil type and the land use on the catchment in the Spring, the mean-weighted value of the erosion coefficient can be determined from the values of specific erosion for these areas.

When data on land use on the catchment in the Spring are lacking the following empirical formula of the erosion coefficients is recommended which was obtained from the analysis of erosion-geomorphological characteristics of small catchments (Frolov, 1961a, 1961b) and improved by results of investigations of the forming of sediment flow of small streams.

$$a = k \frac{H\,(n + n')\,a}{\sqrt[4]{F + 1}}, \qquad (13)$$

where F - catchment area, km^2; H - the depth of the erosion base, km; n - ravine-gully net density, km/km^2; n' - extent of gullying, km/km^2; a - extent of cultivation, parts of unity; and k - a parameter which takes into account climatic, soil and other conditions of forming of the sediment flow.

In one of our previous papers (Frolov, 1961b) it was shown that a similar formula of the erosional-geomorphological coefficient was first proposed by S.I.Sil'vester (1955) as an index for comparing different areas with respect to erosion. As contrasted with Sil'vester's formula, Expression (13) can be used in determining the specific value of water erosion from small catchments.

It is for this purpose that the parameter k is included in Formula (13).

Because in individual cases gully formations (see above) can exert an important influence on the value of sediment runoff from very small (unit) catchments with areas less than 1.0 km^2, Formula (13) includes also the values n' of the extent of gullying. In calculating the erosion coefficient α for small catchments it is recommended that 1.0 be added to the value of F under the radical.

Substituting in Formula (10), (11) and (12) α from Formula (13) we shall obtain the empirical relationships for the calculation of sediment runoff from small catchments and of turbidity of small streams.

$$R_{s,v} = k \frac{H(n + n')a}{\sqrt[4]{F+1}} WI, \qquad (14)$$

$$R_{s,w} = 1.2k \frac{H(n + n')a}{\sqrt[4]{F+1}} WI, \qquad (15)$$

$$\rho_s = 1.2k \frac{H(n + n')a}{\sqrt[4]{F+1}} I \cdot 10^3. \qquad (16)$$

The computations of sediment flow and of turbidity of small streams in the CCP with the proposed empirical formulas presents no particular difficulties. The basic water erosion characteristics of small catchments (area, extent of cultivation, depth of the erosion base, slopes of the surface, ravine-gully density, and extent of gullying) can be obtained from large-scale topographic maps, from land use maps of the collective farms and from aerial photographs by the method outlined in our previous papers (Frolov, 1961b). The area and the extent of cultivation on the catchment are determined by planimetering, with the extent of cultivation of the catchment being

determined in the first approximation by subtracting from the area of the catchment the parts occupied by the ravine-gully net, by meadow, forest, brush, and by agricultural buildings. The depth of the erosion base is determined by the elevation of the highest point in the catchment above the average level of the surface of the reservoir or above the bottom of the channel of the ravine at the planned dam. The ravine-gully density and extent of gullying can be determined most accurately from the land use maps by computing the ratio of their length to the area of the catchment.

B.K.Vakhtin's (1931) formula with a correction coefficient of 1.4 which we obtained by comparing results of computations made with this formula and with a more accurate method of determining mean-weighted values (Frolov, 1961b) is recommended for determining the slopes of the surfaces of small catchments.

$$I_{\text{av.}} = 1.4 \frac{h \sum l}{F}, \qquad (17)$$

where h - contour interval, m; Σl - total length of the contours, km; F - catchment area, km^2; and 1.4 a correction coefficient.

The map of Spring water runoff constructed by K.P.Voskresenskiy (1951) for the forest-steppe and steppe zones of the European part of the USSR and the recommendations of I.N.Sorokin (this volume, page 53) can be used to obtain the mean annual volume of water W.

The values of the parameter k can be determined from the map (Fig. 5) which we constructed for the CCP from data on sediment flow of small streams and on silting of ponds and reservoirs (Appendix 2). They were obtained in a reverse manner with Formula (14).

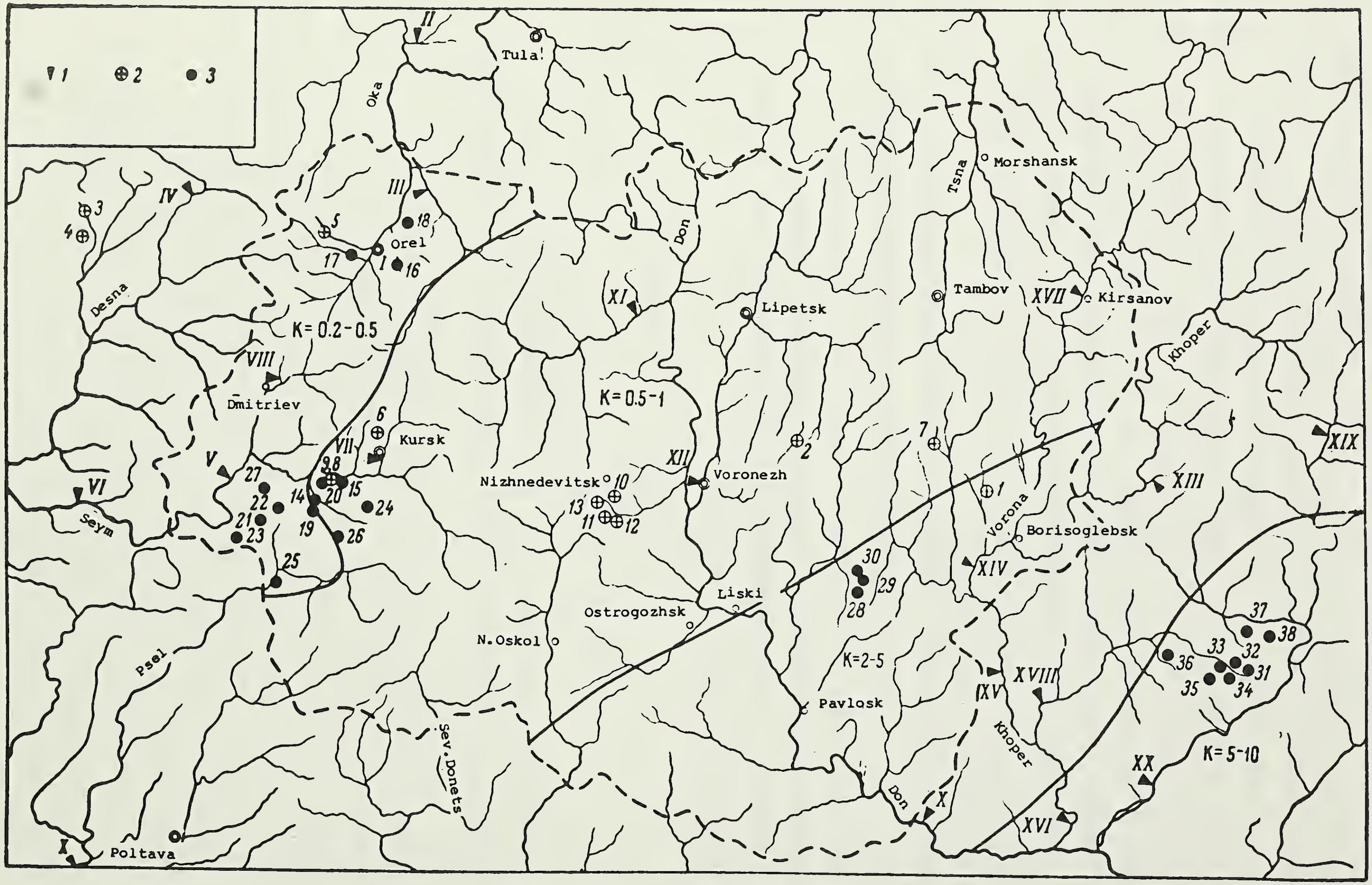

FIG. 5. Parameter (k)

Legend: 1 - observation points on rivers; 2 - on small streams; 3 - on ponds and reservoirs. Numbers at points correspond to data in Appendixes 2 and 3.

According to Figure 5 the values of the parameter k change with regularity over the territory of the CCP from the northwest to the southeast and therefore have a zonal character connected with the basic climatic, soil and other conditions of forming of sediment flow. This change in the parameter k over the CCP agrees quite well with the isolines of the physical-geographical (erosion) coefficient α constructed by B.V.Polyakov (1946) with data on sediment flow of medium and large rivers of the European part of the USSR (Figure 6).

According to B.V.Polyakov's map of the erosion coefficient there are two zones in the CCP. The zone with values of α=1.0-2.0 (for the gray forest-steppe soils) covers a small area in the northwestern part of the Orel and Kursk Provinces (basins of the Oka River with its tributaries and also the catchment of the Svapa - a right tributary of the Seym River). This zone includes also a small northeastern part of the Tambov Province with leached chernozems and with spots of gray forest-steppe soils (middle reaches of the Tsna River). All of the remaining part of the CCP with deep and ordinary chernozems belongs in the other zone with values of the erosion coefficient α =2.0-3.0.

It is necessary to note that because of the still insufficient volume of available data on the sediment flow of small streams and on silting of reservoirs of the CCP it was necessary in drawing the isolines of parameter k on the map (Figure 5) to adjust their direction locally with B.V.Polyakov's values of the physical-geographical (erosion) coefficient α obtained from data on river sediment flow because the essence of these values - the erosion coefficient α (after B.V.Polyakov) and parameter k is one and the same. The map of parameter k was also verified by indirect indices of water erosions (local conditions of forming of sediment runoff: soils, relief, etc.).

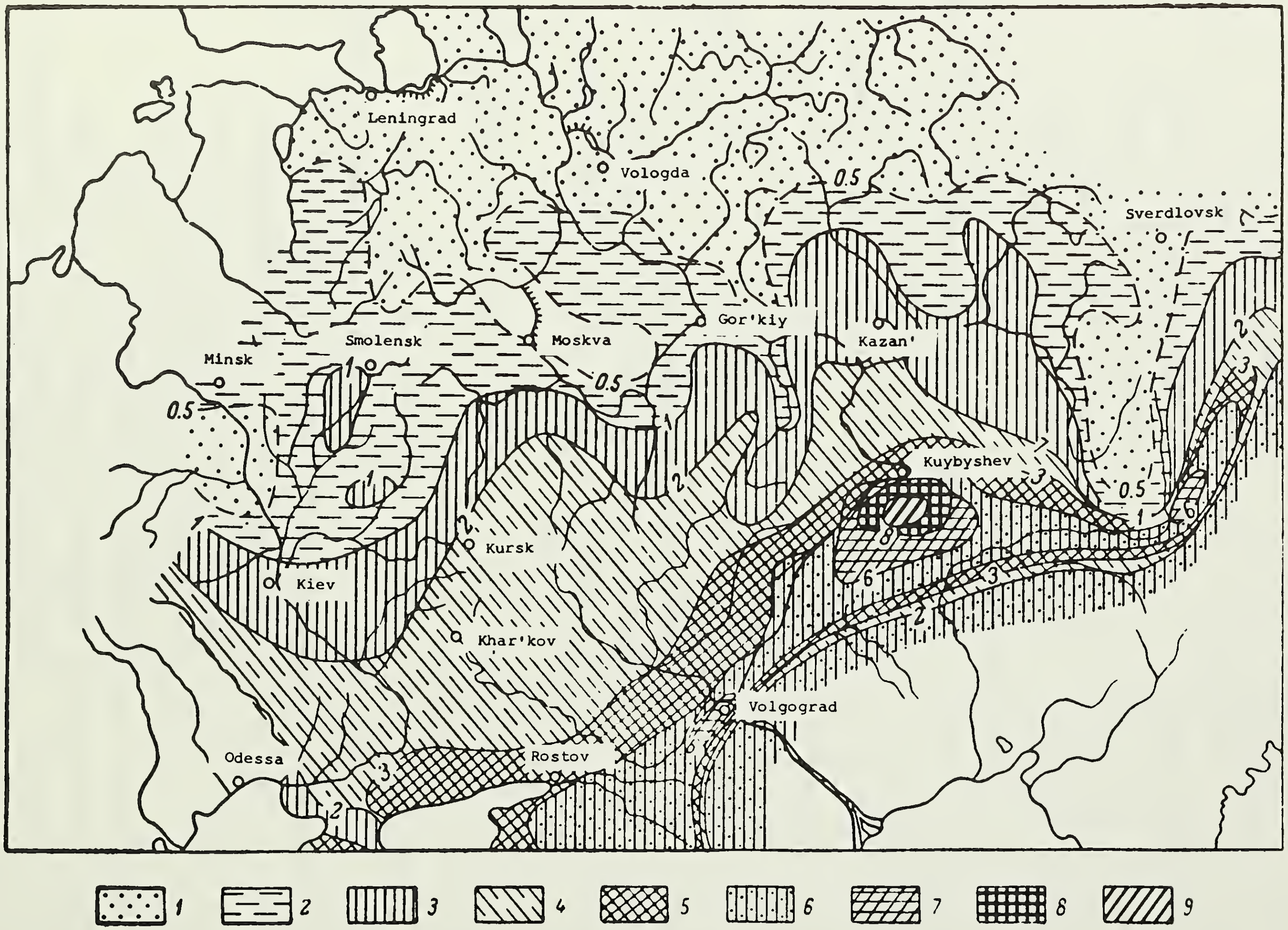

FIG. 6 ISOLINES OF THE EROSION COEFFICIENT
(after B. V. Poliakov)

Erosion coefficient legend: 1 - < 0.5; 2 - 0.5 to 1; 3 - 1 to 2; 4 - 2 to 3; 5 - 3 to 4; 6 - 4 to 5; 7 - 5 to 8; 8 - 8 to 10; 9 - > 10.

In accordance with climatic, soil and other conditions in the forming of sediment flow of small streams in the CCP we delineated three zones of the parameter k.

The first zone with values of k=0.2-0.5 in the main coincides with Polyakov's zone α=1.0-2.0. It covers the northwestern districts of the Orel and Kursk Provinces and includes almost the entire basin of the Oka River except for some headwater tributaries of the Zusha River, the catchment of the Svapa River, and a number of the right tributaries of the Psel River. The soils in this region are sod-podzolic, gray forest-steppe or transitional (podzolized chernozem).

The second zone with values of k=0.5-1.0 is defined in the southeastern part of the CCP by a line between the forest steppe and steppe which, as is known, passes approximately along the line Valuyki-Ostrogozhsk-Borisoglebsk. This zone includes the southeastern districts of the Orel and Kursk Provinces, the northwestern districts of the Belgorod and Voronezh Provinces and also the Lipetsk and Tambov Provinces. The soils of this main part of the CCP are deep and leached chernozems. The third zone with values of k=2.0-5.0 covers the steppe part of the CCP with ordinary chernozems. Ordinary chernozems are more erosion-resistant than the gray forest-steppe soils (Table 4), the sharp increase in the value of k for this zone is, however, explained mainly by the worse climatic and other conditions of the steppe belt which determine the general aridity of this zone - smaller snow accumulation, a thinner natural stand of grass, etc.

It follows from the aforesaid that the values of the parameter k are determined not so much by the erosion properties of the soil as by the climate of the zones. Indeed, while the sod-podzolic and gray forest-steppe soils of the northwestern forest-steppe part of the CCP

are least erosion-resistant, the presence of a large amount of snow in the winter, the frequent forming of an ice crust on the soil, and the accelerated processes of overgrowing of ravines are conducive to the settling out of sediment on slopes, and therefore, to a reduction in the sediment runoff, and correspondingly in the parameter k. On the contrary, the higher sediment flow of small streams of the steppe part of the CCP is explained by the more arid climate resulting in the lack of the protective cover of snow and of vegetation found in the northwestern forest part. Therefore, the values of k here are much higher.

A more detailed distribution of the parameter k over the territory of the CCP than given in Figure 5 can be attained in the future as data on sediment flow of small streams and on silting of ponds and reservoirs are accumulated.

We made an evaluation of some of the best-known and sufficiently substantiated methods of computing sediment runoff from catchments of different sizes in the CCP ranging from catchments of rivers with areas of the order of 400-500 km^2 to catchments of intermittent watercourses with areas less than 1.0 km^2. For this purpose we selected a number of points for which there are available the most accurate and longest records of sediment flow and of silting of reservoirs.

In the calculations of turbidity the following relationships were used: the empirical formulas of B.V.Polyakov (1946), G.V.Lopatin (1952), of M.V.Myalkovskiy and N.I.Drozd (1947), and of S.S.Mikhalchenkov (1949); the method of conversion coefficients the values of which were obtained from data on sediment flow of small streams; and Formula (11) which we obtained with the erosion coefficient computed in one case from data on specific erosion and in another from water erosion characteristics of the catchment.

The shortcomings of existing methods of computing sediment runoff from small catchments were repeatedly pointed out in the literature (Emel'yanov, 1958, Zotov, 1961 and others). In spite of the maximum similarity of our parameters to those of the formulas of G.V.Lopatin, M.V.Myalkovskiy and N.I.Drozd and of S.S.Mikhalchenkov, the results of computations differed considerably from factual data. A quite considerable deviation from factual data (on the average $\pm$150%) was found also in the results computed with conversion coefficients which we obtained from the constructed relationship $\psi = f(\lg F)$ for small streams (Figure 7).

Comparatively fair results were obtained only with B.V.Polyakov's formula. The average deviation from the factual data was $\pm$60-70%.

Quite satisfactory computed values of turbidity of small streams in the CCP were obtained with our proposed method using the empirical relationships (12) and (16) and the corresponding recommendations (see above). The computations were made in two variants: a) from data of specific erosion taking into account land use on the catchment (Table 14), and b) utilizing empirical relationships between the erosion coefficient and the water erosion characteristics of the catchment without taking into account land use (Table 15).

We shall note that the computation of the erosion coefficient from data of specific erosion given in Table 4 involves the difficulty of obtaining information on the land use on the catchment over a long period. Moreover, the land use on very small catchments with areas less than 1.0 km^2 is so changeable from year to year that the possibility of computing the erosion coefficient for them from data on specific erosion and of determining the sediment runoff for a future period is altogether excluded. For

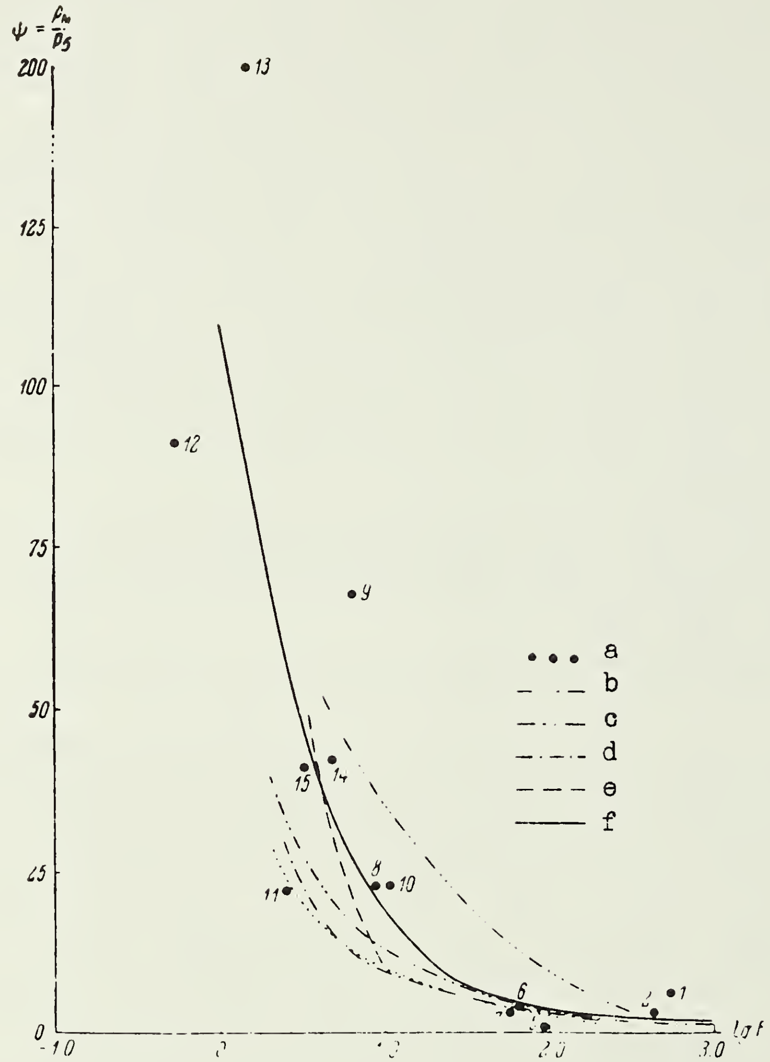

FIG. 7. COEFFICIENTS FOR CONVERSION OF TURBIDITY OF RIVERS OF THE ZONE TO THAT OF SMALL WATERCOURSES $\left(\psi = \frac{\rho_M}{\rho_B}\right)$ FOR DIFFERENT CATCHMENT AREAS (F).

a - after K.P. Voskresenskiy (1951); b - after G.V. Lopatin (1958); c - after K.N. Lisitzyna (1960); d - after M.Ya. Prytkova (1960); e - after I.N. Sorokin and L.V. Yakovleva (1961); f - according to data on flow of suspended sediment in small streams. Numbered dots show points of observations corresponding to data in Appendix 2.

Table 14

CALCULATION OF SEDIMENT RUNOFF FROM SMALL CATCHMENTS IN THE CENTRAL CHERNOZEM PROVINCES TAKING INTO ACCOUNT LAND USE (FROM SPECIFIC SOIL EROSION DATA)

Water body	Soils of catchment	Slope of catchment, I, ‰	Composition of land use on the catchment, %					Erosion coefficient $\varkappa_{av.}$	Turbidity g/m^3		$\rho_\phi - \rho_B$	$\frac{\rho_\phi - \rho_B}{\rho_\phi} \cdot 100\%$
			Fall plowed	Winter crops	Stubble	Long fallow	Forested		Computed ρ_B	Measured ρ_ϕ		
Small Streams												
Barsuk rav.-gag. sta.	Deep chernozems	62	40	20	20	20	0	0.026	1934	1740	−194	11.1
Medvezhiy rav. - gag. station	Same	46	40	11	8	0	41	0.023	1270	1680	410	24.4
Ivkin rav.-gag. sta.	"	78	44	21	0	0	35	0.027	2527	7110	4583	64.4
Churakov rav.-gag.sta.	"	78	48	27	25	0	0	0.032	2995	15300	12305	80.4
												Σ 180.3
												$\delta_{cp.}^{*} = \pm 45.1$
Ponds and Reservoirs												
Borshchenskoe . . .	Deep chernozems	75	45	29	5	20	1	0.030	2700	2780	80	2.9
Uspenskoe.	Same & gray forest-steppe	68	45	30	5	16	4	0.036	2938	2990	52	1.7
Durnovskiy	Deep chernozems	52	50	30	3	15	2	0.036	2059	2020	−39	1.9
Starodubovskiy . .	Ordinary chernozems	23	45	27	10	17	1	0.041	1132	894	−238	26.6
Nizhnekamenskiy . .	Same	28	45	30	10	14	1	0.042	1411	1680	269	16.0
												Σ 49.1
												$\delta_{cp.}^{*} = \pm 9.8$
												Σ = 229.4
												$\delta_{cp.}^{*} = \pm 25.5$

*Average

Table 15

CALCULATION OF SEDIMENT FROM SMALL CATCHMENTS IN THE CENTRAL CHERNOZEM PROVINCES WITHOUT CONSIDERING COMPOSITION OF LAND USE (FROM WATER EROSION CHARACTERISTICS OF CATCHMENTS)

Water body	Catchment area, F, km^2	$\sqrt[4]{F+1}$	Erosion base depth H, km	Ravine-gulley density, n km/km^2	Gulley density n', km/km^2	Extent cultivated, parts of unity	Slope of catchment I, ‰	Parameter k	Turbidity g/m^3: Computed ρ_B	Turbidity g/m^3: Measured ρ_Φ	$\rho_\Phi-\rho_B$	$\frac{\rho_\Phi-\rho_B}{\rho_\Phi}$ 100%
Small Streams												
Karachan - Aleshki	565	4.88	0.061	0.68	—	0.80	27	3.00	661	638	—23	3.6
Khava - Il'inovka	426	4.54	0.053	0.68	—	0.75	27	1.00	191	250	59	2.4
Kur - Kazatskaya	66.0	2.85	0.089	1.07	—	0.40	56	0.75	655	863	208	24.1
Kletsnya - Rakitno	58.0	2.77	0.057	0.66	—	0.65	24	0.75	190	152	—38	25.0
Barsuk - gaging station	10.7	1.82	0.087	0.88	—	0.80	62	0.75	1900	1740	—160	9.2
Medvezhiy - gaging station	2.55	1.37	0.071	1.12	0.38	0.59	46	0.75	1900	1680	—220	13.2
Ivkin - gaging station	0.55	1.11	0.054	1.71	0.98	0.65	78	0.75	6040	7110	1070	15.0
Churakov - gaging station	1.56	1.26	0.066	1.54	1.54	0.61	78	1.00	9170	15300	6130	40.1
												Σ 132.6 $\delta_{cp.}^{*} = \pm 16.6$
Pond and Reservoirs												
Malaya Kulikovka	18.8	2.11	0.060	1.00	—	0.80	43	0.50	593	600	7	1.2
Ol'shanskie Vyselki	3.43	1.45	0.062	1.02	—	0.90	70	0.50	1390	1550	160	10.3
Pervyy Voin	20.4	2.13	0.090	1.00	—	0.90	35	0.50	798	772	—26	3.4
Borshchenskoe	48.0	2.65	0.086	1.37	0.19	0.78	75	0.75	2700	2780	80	2.9
Uspenskoe	33.2	2.42	0.079	1.33	0.18	0.79	68	0.75	2390	2990	600	20.1
Durnovskiy	15.7	2.02	0.087	0.92	0.08	0.89	52	0.75	1520	2020	500	24.7
Murynovskiy	5.90	1.62	0.070	1.19	—	0.81	87	0.35	1530	1770	240	13.6
Viktorovskiy	5.20	1.58	0.042	1.06	—	0.90	66	0.50	1780	1530	—250	16.3
Kondratovskiy	8.35	1.75	0.062	1.20	—	0.88	91	0.35	1420	1420	0	0
Bashkatovskiy	4.00	1.50	0.060	1.75	—	0.80	128	0.50	4300	5260	960	18.3
Starodubovskiy	22.7	2.21	0.030	0.57	0.01	0.73	23	3.50	560	894	334	37.3
Nizhnekamenskiy	42.5	2.57	0.082	0.68	0.07	0.76	28	3.50	2120	1680	—440	26.2
												Σ 174.3 $\delta_{cp.}^{*} = \pm 14.5$
												Σ 306.9 $\delta_{cp.}^{*} = \pm 15.3$

this reason the computations with this variant were made only for some cases. The average deviations from factual data proved to be = ±25.5%.

In accordance with I.Z.Kuznik's (1958b) recommendations the erosion coefficient α_{av} for the principal types of agricultural land in all cases were determined as mean-weighted values by the formula:

$$\alpha_{av.} = \frac{\alpha_1 f_1 + \ldots + \alpha_n f_n}{F}, \qquad (18)$$

where α - specific erosion from different agricultural land; f_i - part of the catchment in a given land use, part of unity; F - total area of the catchment, equal to 1.0.

The erosion coefficient α_{av} for the catchment of the Uspenskoe Reservoir was made somewhat more precise by taking into account the percent ratio of gray forest-steppe soils to deep chernozems which, according to our data (Frolov, 1963), occupy 16 and 84% respectively of the catchment area. It was assumed that the land use pattern was the same on both soil types.

Thus, for the main part of the catchment of the Uspenskoe Reservoir with deep chernozems

$$\alpha' = (0.05 \times 0.45 + 0.025 \times 0.30 + 0.005 \times 0.05 + 0.002 \times 0.16 + 0.0 \times 0.04) = 0.031.$$

For the remaining area with gray forest-steppe soils

$$\alpha'' = (0.10 \times 0.45 + 0.05 \times 0.30 + 0.02 \times 0.05 + 0.005 \times 0.16 + 0.0 \times 0.04) = 0.062.$$

For the catchment of the Uspenskoe Reservoir as a whole the value of the erosion coefficient is

$$\alpha_{av.} = \frac{\alpha' \cdot 0.84 + \alpha'' \cdot 0.16}{1.0} = 0.036.$$

The computation of the erosion coefficient α for all catchments without exception from the empirical relationships presented no particular difficulty. The large-scale maps constructed as a result of an erosion-hydrographic survey of the catchments in the Kursk and Voronezh Provinces (Frolov, 1961b) were used to obtain the erosion geomorphologic characteristics of some of these catchments. For the remaining catchments, topographic maps were used. In the latter case (from topographic maps) only the extent of gullying could not be determined and was assumed to be zero for the uninvestigated catchments. The mean-weighted slopes of the surface of the catchment was determined by B.V.Vakhtin's formula with a correction coefficient of 1.4, the total length of the contours for each catchment being measured on the same map.

In the determinations of the parameter k the map given in Figure 5 was used.

The average deviation of turbidity of small streams computed with the empirical relationship (16) from the measured was ±15.3%.

And so, for the determination of the long-term mean annual turbidity of small streams in the CCP, the empirical relationship (16) is recommended which is obtained by the analysis of the conditions of forming of sediment runoff and is verified by the computations.

This relationship can be used subsequently in the computation of turbidity of small catchments lying in other regions of the USSR, provided data on the value of the geographical distribution of k which is zonal in nature are available.

When long records of land use on the catchments **are** available the obtained results can be compared by computing the mean-weighted value of the erosion coefficient from specific erosion. The conversion coefficient method

can, in individual cases be utilized in verifying the computed turbidity of small streams.

Measures for the Protection of Small Reservoirs in the Central Chernozem Provinces from Silting

One of the principal causes of silting of ponds and reservoirs in the CCP is the entry of products of water erosion from the catchments; such silting frequently puts reservoirs quickly out of commission. Water erosion also causes tremendous damage to the national economy. The protection of reservoirs from silting could, in individual cases, be limited to putting into effect a number of measures in their immediate vicinity. However, in addition to protecting reservoirs from silting, combating water erosion on catchments is, in itself, an important task of the national economy. Therefore, measures for the protection of reservoirs from silting must as was pointed out in the "Resolutions of the Interdepartmental Conference on Small Reservoirs of the Plain Provinces and on Their Utilization" (1959) be of a complex nature and must be directed in particular towards the elimination of the causes of water erosion from catchments. According to the place of their application they can be divided into measures applied on the catchment and near the reservoir. As far as measures applied on the catchment are concerned they must be provided for in the construction plans of reservoirs and must be implemented by the agricultural agencies. Control measures in the immediate vicinity of reservoirs must be mandatory in the planning and construction of ponds and reservoirs.

1. Control Measures on the Catchment

In accordance with V.V.Dokuchaev's program of erosion control the regulation of surface runoff on catchments must proceed along three "lines of defense": 1) decreasing water runoff immediately on the spot by increasing the

water-absorbing capacity of soil; 2) water retention on slopes by creating microrelief and by planting of vegetation; 3) interception of parts of the runoff in the ravine-gully net by building artificial reservoirs (Armand, 1955). All this is accomplished by the application of a system of administrative-economic, agrotechnical, phytomeliorative, and hydrotechnical practices on the catchment. In applying erosion control practices on catchments it is necessary to be guided by the resolution of the Expanded Plenum of the Permanent Interdepartmental Scientific Research Commission on Combating Soil Erosion at the Dokuchaev Soil Institute of the Ministry of Agriculture USSR which took place on 27-29 March, 1962 in Moscow and by the several guides of provincial agriculture administrations on combating water erosion.

1. Administrative-Economic Measures. During the periods of intensification of the complex mechanization of agricultural production the success of the application of erosion control measures will depend on correct organization of the territory which could ensure a rational distribution of the three principal types of land (fields, meadows, and forests) and also of all means of regulation of surface water runoff.

The problems of antierosion organization of a territory have at different times been elucidated in the works of A.C.Kozmenko (1937,1949), S.S.Sobolev (1939,1940), S.I.Sil'vester (1949,1962), I.A.Sus (1949), D.L.Armand (1955), T.F.Antropov and D.L.Armand (1956) and of some other investigators.

A.C.Kozmenko (1937) was the first to propose, on the basis of many years work of the Novosil'skaya Agro-forest Reclamation Station, that the entire area of a catchment be divided into three unequal parts: the part near the watershed divide (slopes less than 2°), the part near the drainage net (3-6°) and the hydrographic part (greater than 6°.

It is considered that the grain and row-crop fields must be located on the land near the watershed divides which in the CCP constitutes 50-70% of the area of catchments. On the land near the drainage net (15-30%) soil protecting (forage) rotations with perennial grasses must be used; the hydrographic land (6-15%) must be subjected to phytomelioration.

The work of other investigators points to the importance of land-use planning, of correct sizes of fields, correct location of boundaries and of roads, of forest belts, and of a differentiating approach to the utilization of eroded soils, etc. To carry out the administrative-economic measures in accordance with resolutions of the Expanded Plenum of the Permanent Interdepartmental Scientific-Research Commission on Combating Soil Erosion at V.V.Dokuchaev Institute of the Ministry of Agriculture USSR (1962), a map must now be prepared for each farm on which must be shown nine principal classes of land constituting the following three groups: 1) intensively cultivated land, 2) land suitable for limited cultivation, and 3) land unsuitable for cultivation. It is recommended that each erosion control practice be worked out as applicable to specific conditions of the delineated areas.

Our investigations (Frolov, 1961b, 1963) show that in accordance with the peculiarities of the manifestation of water erosion, plans for catchments of small reservoirs in the CCP must, in addition, define: very gently sloping ridge areas (less than 2°), gently sloping intermediate areas (2-4°), steep areas near the drainage net (4-8°) and slopes of the ravine-gully net (more than 8°). Large scale contour maps can be utilized for this purpose. The delineation of the indicated areas on the map can be done with scaled overlays.

The steep areas near the drainage net (4-8°), the most dangerous from the erosion standpoint, which in the

CCP constitute 10-20% of the entire area of the catchments must be excluded from the basic crop rotations and must be utilized for soil-conserving forage rotations with 50-60% of cereal-legume plants and perennial grasses. The slopes of the hydrographic net which in the CCP constitute 7-15% of the entire area of the catchment must be subjected to phytomelioration.

Under conditions of the CCP where up to 80-90% of the catchment areas are cultivated and where land in forage crops is excessively grazed, the most complicated problem is the protection of paddocks and pastures from water erosion. The solution of this problem is possible only by a progressive change to complete or partial stabling of cattle (Sil'vester, 1962).

2. Agrotechnical Practices. Agrotechnical methods of cultivation and of growing agricultural crops and also methods of water retention, regulation of snow melting, and of water runoff must be an inseparable part of the system of erosion control measures.

The principal purpose of agricultural practices in an agricultural system is, as a rule, to increase soil productivity and the yields of agricultural crops. Of the entire diversity of scientifically substantiated agrotechnical practices of cultivation and of growing of agricultural crops which are the field of investigation of agricultural workers, we shall point out that according to these investigations ("Systems of Agriculture in the Central-Chernozem Belt", 1961), the principal methods of restoration of a stable crumb structure of the soil in the CCP are periodical deepening of the plow layers to 30-40 mm, and the seeding of annual and perennial structure-forming plants (legume-cereal mixtures). The latter is a component part of the scientifically substantiated crop rotations for various soil-climatic conditions. We shall point out also that the increase in erosion -resistance of the soil

by structure-forming can, in individual cases, be achieved also by means of polymers: polyacrilamide, polyacrilnitrile and of other substances (Matchanov, 1962; Tan Ke li, 1962).

However, in the system of erosion control practices on catchments, methods of regulation of surface runoff for the control of water erosion are of direct importance.

As is known the development of methods of regulating surface runoff and of combating water erosion began in Russia in the second half of the XIX Century. M.I.Afonin (1771) was the first to pose the question of furrowing the fields. Somewhat later A.T.Bolotov (1781) recommended the use of diversion ditches in combating the growth of ravines. According to the description of N.O.Arnol'd (1840) such work was done by N.N.Shishka in the Nevel'skiy District of the Vitebsk Province. According to N.N.Shishka's idea these ditches located at right angles and along the contours were supposed to prevent the washing-out of fertilizer, to retain the moisture of summer rains, aid in the accumulation of snow for the protection of winter crops from heaving, and to improve the physical properties of the eroded soils on the slopes.

The further development of methods of combating water erosion is closely connected with measures used in the struggle for moisture and plant food. In a number of papers A.N.Shishkin (1873a, 1873b, 1874 and 1876) recommended among other methods developed by him for combating droughts on slopes, the so-called "trapping" (open) ditches connected with tiles for the uniform distribution of the retained moisture. In recommending these methods of combating drought A.N.Shishkin pointed out also the advisability of deep plowing before the winter or subsoiling once in 4-5 years.

A.N.Shishkin's suggestions were utilized in the experiments of A.A.Izmail'skiy (1894) which confirmed that

deep fall-plowing of fields in the Ukraine increased the soil moisture to a depth of 2 m. P.A.Kostychev (1893,1898) pointed out also that under conditions of the chernozem provinces cultivation of the soil in the fall and the accumulation of snow on the fields are important means of increasing soil moisture.

In 1881-1882 an expedition under the direction of I.I.Zhilinsiy (1892) used for the first time in the arid provinces of Russia (particularly in the former Samara Province) retention of melt waters by earthen ridges in connection with flood irrigation. The idea of retaining surface water on fields by means of earthen ridges 0.3 m high was advanced simultaneously by P.V.Yankovskiy (1891,1902,1914) who showed that moisture conservation must be practiced in all provinces of Russia's steppe belt including the district of the CCP where the annual precipitation is less than 500 mm.

V.V.Dokuchaev (1892, 1894) assigned great importance to measures of retention of surface waters on fields. In the CCP he improved P.V.Yanovskiy's method by grassing and afforesting the ridges. In addition, V.V.Dokuchaev proposed a number of erosion control measures which included the planting of field, forest shelter belts, the building of ponds at the heads of gullies and ravines, the building of fences to protect the ravines from washing out.

The system of the indicated methods of retention of surface water was partially applied by the expedition under the direction of N.N.Annenkov (1893) which was organized for work in the Central Provinces in Russia in connection with the drought and crop failures. A member of this expedition P.P.Tikhoobrazov (1893) improved the methods of ridging of fields in the Tambov Province by suggesting higher ridges than did P.V.Yankovskiy, ridges - terraces with a height of 0.7 m and side slopes of 1:4 to 1:5 for

convenient passage of agricultural implements in tilling the soil. It should be said that P.P. Tikhoobrazov's method using ridge - terraces with fields laid out along the contour to reduce runoff and water erosion found wide application later in the USA under the name of strip cropping.

The ideas of P.V.Yankovskiy and of V.V.Dokuchaev were later accepted by V.M.Bortkevich (1915) who proposed the construction of special ditches with ridges for combating the growth of gullies. Bortkevich's ridges are frequently used at the present time.

A.A.Shalabanov (1903) having been the first to prove that frozen soil is capable of absorbing melt water recommended plowing of the fields "in checkerboard fashion" to form a series of basins for the retention of water on the fields instead of the expensive forest planting. A.A.Shalabanov also improved N.N.Shishka's method by replacing the crossing ditches with cherckerboard furrowing.

A.A.Shalabanov's method was later (since 1926) improved on the Novosil'skaya Gully Experiment Station (Kozmenko, 1937) and at the present time is used in the cultivation of many fields under the name "crossing fall-plowed land." Furrowing of fields and check furrowing ("checkerboard") under the name of "basin listing" and "contour listing" found wide application in the agriculture of the United States.

After the October socialist revolution a number of scientific institutions and many agricultural specialists were engaged in the development and application of methods of accumulating and storing moisture in the soil. A great deal of attention was paid to the development and testing of different erosion control methods. In this field we shall note the successful work of the All-Union Scientific Research Agroforest Reclamation Institute (VNIALMI), of the All-Union Scientific Research Institute of Hydrotechnics and Reclamation (VNIIGiM), of the V.V.Dokuchaev Soil Institute, of the V.V.Dokuchaev Institute of Agriculture

of the Central-Chernozem Belt, and of a number of other scientific institutions who conducted successful work over many years.

The methods of management of surface runoff developed by the Novosil'skaya Gully Experiment Station (now the Agroforest Reclamation Station) of VNIALMI, by the Kursk Zonal Experiment Reclamation Station (KZOMS) of VNIIGiM, by the V.V.Dokuchaev Agriculture Institute of the Central-Chernozem Belt and by other institutions for the CCP constitute an important contribution in the field of combating water erosion.

At the present time the most available and widespread methods of retaining water on the fields is contour plowing in the fall which was recommended by A.N.Shishkin (1873b), A.A.Izmail'skiy, 1892, P.A.Kostychev (1893) as far back as the end of the XIX Century. Cross-slope or contour cultivation of fields found wide application also in the United States. According to the data of J.Stallings (1945), Van Doren and others (1950), and of G.Free (1956), contour cultivation on gentle slopes considerably reduces water runoff and erosion and increases yields of agriculture crops by 10%. However, contour cultivation in the United States is considered impractical on dissected slopes because with this method many dead furrows are formed. In addition, the investigations of Van Doren and Bartell (1956) in the U.S.A. showed that on slopes of 15° cross-slope (contour) cultivation completely loses its erosion control effectiveness. D.Smith and D.Whitt (1948) arrived at similar conclusions even earlier. According to the investigations of B.Kozlik (1956) in Eastern Slovakiya contour plowing on steep slopes is to a large extent conducive to the forming of gulleys.

Therefore, the effectiveness of cross-slope plowing on slopes must be evaluated in every individual case.

At the present time it is established in the USSR ("Systems of Agriculture in the Central-Chernozem Belt", 1961) that cross-slope cultivation in the CCP gives positive results only on slopes less than 2°. On steeper slopes the furrows are quickly filled with water as a result of which over-topping and destruction of the ridges occurs. In individual strongly dissected districts of the CCP it is also difficult to plow across the slopes. For this reason on areas of such catchments (60-70% of the plowed land) oblique instead of contour plowing is recommended (Surmach, 1961).

Aiming at more effective accumulation of snow and retention of runoff water on fields G.G.Kabanov (1943) and M.T.Strukov (1944) and a number of other investigators recommended ridging of fields along with cross-slope cultivation.

Numerous recent investigations of G.A.Presnyakova (1955), I.P.Sukharev (1955b), I.A.Tereshchenko (1955), V.V.Yarovenko and I.S.Aliev (1956), G.P.Surmach (1957), I.A.Kuznik and O.S.Sinel'shchikova (1958), B.F.Trushin (1960), P.S.Tregubov (1961), and of other scientists showed that contour ridge plowing of fall-plowed land is an important practice for reduction of overland flow and for prevention of water erosion.

Good results in accumulation and conservation of soil moisture, in reducing water runoff, and in decreasing water erosion are obtained by contour cultivation with subsoiling; (Bityukov and others, 1953; Ivanov, 1953; Zaslavskiy, 1954; and Levchenko, 1958); by deep loosening of the soil with plows without moldboards by T.S.Mal'tsev's method (Kozmenko, 1956 ; Lysak, 1958; Yarovenko and Suchalkina, 1958; and Gutsaki, 1959) and with some other methods of subsoil cultivation. However, under conditions of the strongly dissected relief of the CCP the use of the indicated methods of cultivation of fields do not always lead to desirable results in combating water erosion on

compounded slopes. On such slopes the V.V.Dokuchaev Agricultural Institute of the Central-Chernozem Belt recommends basin listing. Although the methods of cultivation with microponding is still under investigation, there are positive results of its application (Boyko and others, 1956; Skachkov and Suchalkina 1959; and Sokolov, 1959).

Because the common methods of loosening the soil by plowing lead to its pulverization and to decreasing infiltration, chiseling and mole plowing of the soil must be considered promising. Chiseling of the soil as a method of moisture conservation by furrowing across the slopes with a chisel was proposed by A.V.Sobesskiy (1938), was improved by P.S.Volkov (1954) and verified by M.S.Tsyganov (1958) under conditions of the Voronezh Province on virgin-layland which is now in pasture. The so-called "vertical mulching" (J.Spain and J.Ligidhal, 1960) consisting of filling the cracks with mulch was developed as a variant of the chiseling method in the USA and is used on sloping land in fruit trees and berries.

Tests of the chiseling method on the fields of the KZOMS showed that chiseling across the slope to a depth of 40-50 cm is conducive to the accumulation of moisture in the soil in the Spring but during the dry summers causes drying of the soil through the open cracks. For this reason a method of mole plowing the soil which, as is known, was proposed in its time by A.N.Shishkin and consists of cutting mole-drains to a depth of 40-50 cm simultaneously with plowing by means of a pointed cylinder on the plow share (Ginaylo, 1956) was developed and applied by the KZOMS. According to S.S.Sololev's (1947) conclusions mole plowing does to a certain extent imitate nature in the virgin steppe with its numerous ducts of burrowing animals. The high effectiveness of mole plowing as a new method of combating

erosion and drought is pointed out in the papers of Yu.A.Nosulenko (1948), S.V.Astapov and V.I.Bobchenko (1950), I.Kh. Beskov (1954), V.I.Bobchenko (1954), P.Truss (1955), and of other investigators.

For more complete retention of surface runoff water on fields it is recommended that all the above-enumerated methods of its regulation be employed in combination with snow retention (Dokuchaev, 1892; Kostychev, 1893; Astapov and others, 1951, Rikhter, 1953; Byalyy and Kabanov, 1954; and Shul'gin, 1954). Snow retention is conducive to better moistening of the soil, and to decreasing the depth of its freezing, and protects winter crops from freezing (Mosolov, 1925, Neustruev, 1930; Prozorovskiy, 1940; and others). As we pointed out above snow retention is also a means of creating a protective cover over the fields which in the springtime protects the soil from water erosion and aids in the settling out of products of water erosion.

Snow retention as a method of regulating surface water runoff has long been known in agricultural practice. The beginning of its application is connected with the development of the method of retention of surface runoff. However, as a result of the application of one or another method of fall plowing conditions are created on the micro-relief of plowed land which result in only partial snow retention of the field. Larger accumulations of snow can be achieved by compacting artifically with rollers, by snow plows of the ridging type and by the creation of additional obstacles in the path of its blowing. Such obstacles on agricultural fields can be plant residues (stubble, mulch); high stemmed plants (corn, sunflower); fences of brush, straw, stems of sunflower and corn; and sodded and forested parts of the slopes.

Snow retention must be carried out taking into account the prevailing direction of winter snow storms. Because in the CCP southerly winds prevail during this time of the

year, snow retention is recommended principally on windward slopes of southern exposure. On the northern snow-drifting slopes it is necessary to regulate the melting of snow by blackening the soil in strips with ashes, crushed peat, etc. Snow retention is carried out principally on the lower part of insolated slopes while regulation of snow melting is done on upper parts of the shaded slopes.

3. Forest-meadow amelioration and hydrotechnical measures. Seeding and afforestation of slopes are important components of the system of erosion control measures on catchments. The role of the vegetation growing on slopes as a protective cover against water erosion is universally known. Grass and arboreal vegetation firms up the soil particles with its roots and thereby protects it from washing. The upper part of the vegetation increases the roughness of the soil surface and aids in the dispersion of the streamlines, in the reduction of the velocity and in the settling out of products of water erosion. A dense vegetal cover is good protection of the soil from water erosion. Soil covered with dense vegetation is usually not subject to destruction even on steep slopes.

According to the data of the Novosil'skaya Zonal Agroforest Reclamation Experiment Station (Glybin, 1958), a meadow strip of a cereal-mixed grasses-association 30-40 m wide in the Orel Province protects the soil well from washing in the Spring and settles out a considerable (up to 80-90%) amount of the soil particles washed off above-lying areas. According to observations at the Kletskiy Gully Experiment Station in the Volgograd Province (Dukhnov and Glybin, 1961) perennial grasses on slopes of $5^{\circ}43'$ reduced soil erosion during summer rains 30-150 fold as compared with fallow; in the Springs of 1947 and 1948 there was practically no erosion from perennial

grasses. The specific erosion from areas in grass (Table 4) is generally negligible.

Investigations over many years on the Ukraine (Cherkasova, 1959) have shown that seeding of slopes of gullies is conducive not only to the termination of erosion and of washing but also to enhancing the erosion resistance properties of the soil.

The best method of utilizing the slopes of the ravine-gully net for hay and pasture is considered to be accelerated seeding, i.e., the seeding of perennial grasses into sod. In seeding slopes it is recommended to use grass mixtures of 3-5 legumes and loose-tillering and rizom cereals. The grasses must have a long life, must be capable of producing a dense stand and a stable sod. The composition of grass mixtures in seeding slopes is selected according to the recommendations of G.Ya.Bronzova (1952), V.K.Dukhov and T.G.Glybin (1961), N.C.Kamyshev (1961), and V.A.Cherkasova (1962).

Depending on local conditions, exposure of slopes, their degree of destruction, and moisture conditions the following are recommended: a) on chalk and limestone outcrops and also on slopes of southern exposure - various types of quack grass (creeping, medium, hairy and filamentous), of "zhitnyak" (crested and tegular), steppe brome grass, chalk fescue, yellow alfalfa, sainfoin and others; b) on wetter slopes of northern exposures smooth brome meadow clover, yellow alfalfa, Kentucky bluegrass, and ryegrass can be added to the different types of quack grass and of "zhitnyak", bloomy koeleria, fescue, and lupine.

Lowland cereal grasses (Kentucky bluegrass and narrow leaved meadow grass fescue, and others) which form a dense resilient sod are the best soil stabilizers. Loose-tillering cereals have poorer protecting characteristics but with them in the mixture a quick closure of the canopy is achieved. Rizom grasses (for instance, smooth brome) cover

the soil surface with runners which grow every year from the joints of the rizoms. With these grass mixtures a firm sod is created.

Because eroded soils of the slopes lack the principal plant food substances it is necessary to use mineral fertilizers for the growth of the grasses just like for other crops. According to the investigations of V.A.Cherkasova (1959) phosphate-potash fertilizers increase the yield of grasses by 45-65%. With the application of 20 tons/ha of manure the increase in yield reaches 40-90% depending on soil moisture. The effect of the applied fertilizer on plant growth persists also in the following 1 to 3 years. The greater the erosion the stronger is the response of the plant to the fertilizer.

The erosion control properties of vegetation form the basis in the USSR and abroad (principally in the USA) of a number of methods of protecting the plowed surface of the soils from water erosion including: cropped and green manure fallow, mulching, strip cropping, buffer and stubble strips, seeding in stubble, etc.

Of the entire multiplicity of known methods of protecting the bare soil from water erosion which are based on the erosion control properties of vegetation, cropped fallow is now of great importance. Vetch-oat or cow pea-oat mixtures, legume grass mixtures, rye, and corn for silage are widely used as fallow occupying crops in the CCP. Experimental and scientific agricultural agencies of the CCP (particularly the Dokuchaev Agricultural Institute of the Central-Chernozem Belt, the L'gov Selection Experimental Station in the Kursk Province, the Tambov Provincial Experiment Station and others) have proven that it is possible to obtain high yields of winter crops planted after cropped and green manure fallow. Therefore, with further intensification of agricultural production in our country clean fallow must

wherever possible be fully replaced by cropped and green manure fallow in order to protect the soil from water erosion.

One of the most important means of protecting the bare soil from water erosion can be the covering of it with wastes of agricultural production (stubble, straw, manure, plant residues after haying, etc.) which is known by the name of mulching.

Mulching found the widest application in agricultural practice of the USA where the various (from straw and manure to plastic films) materials, their amounts, methods of incorporating them in the soil, and dates of mulching were investigated in sufficient detail and are recommended (Kidder et al, 1943; Lunt, 1955, Browning et al, 1953, 1947, Verma and Kohnke, 1951). Manure and straw commonly used to cover 2/3 to 3/4 of the bare surface of the soil immediately after planting winter crops are the most widely used mulching materials. According to A. Verma and G. Kohnke (1951) a layer of mulch (3.75-5.0 tons of straw or 10.0-12.5 tons of manure per hectar) reduces the freezing of the soil but does not hinder its aeration. Like stubble rotting residues of straw and manure on the surface of the soil are capable of accumulating snow on the fields.

According to the data of G.I.Shvebs (1962) who conducted a study of the effect of mulch on runoff and erosion, a cover of straw of only 15 g/m^2 (0.15 tons/ha) reduced runoff almost three-fold and erosion thirty-fold. With a straw cover of 2.5 tons/ha erosion is almost completely suppressed.

The data of a number of American scientists (Borst and Woodburn, 1942; Duley and Russell, 1942; Peel, 1943, Free, 1953 and others) show that mulching also protects

protects the soil from the so-called "structural erosion" when acted upon by the wind and raindrops.

Thus the value of mulching in protecting the soil from erosion is indisputably enormous. Mulching can, however, also reduce crop yields in regions of excessive moisture. With rapid decomposition of plant residues on the surface or near it a great deal of oxygen is absorbed. Oxygen deficiency and the excess of carbon dioxide in the soil are increased as a result of the high moisture content of the soil. This leads to a reduction of the amount of soil air. In addition, the micro-organisms which decompose plant residues use large quantities of plant food especially of available nitrogen. Temporary exclusion of elements of plant foods as well as unfavorable aeration can lead to a reduction in yields of agricultural crops planted on mulched soils. Therefore, when applying mulch it is necessary to loosen the soil to a greater depth and the mulching must be done immediately after seeding or prior to emergence. All these requirements of mulching must be verified under specific conditions.

In the USA strip cropping is widely used on eroded soils with slopes of 6-15% (Tower and Gardner, 1954). These are 20-40 m strips of row crops alternating with crops which do not require clean cultivation. The latter forms the so-called "buffer strips". The difficulty of cultivating the crops growing in the strips is to a large extent compensated by the protection of the soil from washing.

In the USSR strip cropping has not been used as widely as the USA, however, their use is increasing from year to year. At the present time, the soil erosion laboratory of the Dokuchaev Institute together with the Agrobiological Station of Moscow University are conducting an investigation

of the use of mixed cropping in combating water erosion. In mixed cropping the plant densities are higher, the land occupied by the plants is used for a longer period and is plowed less frequently. Results of observations of soil erosion show the great effectiveness of this method of combating water erosion (Presnyakova and Yurin, 1961).

Afforestation of slopes give the best results in the protection of the soil from washing. The idea of creating forest shelter belts in the CCP was, as is known, applied in practice by V.V.Dokuchaev at Kamennaya Steppe. In his remarkable plan of reforming nature (1892b), the role of the forest as a regulator of surface runoff was given the leading place.

At the present time, there are, in the CCP, a number of scientific institutions with much experience in shelter belt afforestation. They include the Novosil'skaya Zonal Agroforest Reclamation Experiment Station in the Orel Province, the Dokuchaev Agricultural Institute of the Central-Chernozem Belt, the Voronezh Forest Experiment Station and a number of others. The work of A.S.Kozmenko (1937b), G.A.Kharitonov (1940, 1950, 1958), G.F.Basov (1948), I.P.Sukharev (1955), and of other investigators at these stations showed that forest plantings favorably affect the water regime of agricultural fields by absorbing a considerable part of the surface runoff and sharply reducing soil erosion. Forest belts aiding in the absorption of water and its infiltration into the soil also create conditions for a higher level of ground water (1954).

According to the data of G.F.Basov (1948) and I.P.Sukharev (1955) the coefficients of runoff from catchments with different forest cover at Kemannaya Steppe, Voronezh Province were on the average for the 10-15 years of observation as follows: from an open catchment 0.51; with afforestation of 6% - 0.32 and with 18% - 0.16.

Approximately the same data on the hydrologic role of forests as an accumulator of water were obtained by the Laboratory of Forestry of the Academy of Sciences, USSR (Molchanov, 1957, 1962) by observation at the Tellermanovskiy Experimental Forest (Voronezh Province) and in the Derkul'skaya Steppe (Lugansk Province).

The soil-protecting role of the forest is especially great. According to the data of the Dokuchaev Agricultural Institute of the Central-Chernozem Belt (Sukharev, 1960), average erosion at Kamennaya Steppe for eleven years of observation (1948-1958) was 40-100 kg/ha on forested slopes as against 2500-4500 kg/ha on unforested areas. According to three years of observations of A.N.Green in the Kursk Province (1963) the coefficient of runoff from forested areas did not exceed 0.1 and soil erosion was entirely nonexistent (Appendix I). According to observations of I.A.Kuznik in the Trans-Volga (1961), erosion from forested areas was also practically zero.

In the winter forest belts create conditions for additional accumulation of snow in the fields, and in the summer they protect them from the action of drying winds. On the afforested area in the CCP many collective farms obtain increases in yields of grain ranging from 1.5 to 12.3 ct/ha (Braude, 1959).

According to the data of G.A.Kharitonov (1958), A.C.Kozmenko (1959), I.D. Braude (1959), V.A.Kargov (1961), and of other investigators three types of forest belts are usually recommended for planting on catchments; plantings near ravines along the edges, water regulating plantings in the middle of the slope, and field shelter belts on the ridge land. Depending on the dissection of the relief the following are the most frequently used in the CCP:

1) on strongly dissected catchments (ravine-gully density of 1.0-1.5 km/km^2, length of overland flow not greater

than 500 m) - gully forest belts planted near the ravine and also plantings in the ravines themselves;

2) on moderately dissected catchments (ravine-gully density 0.5-1.0 km/km^2, length of overland flow 500-700 m) - water regulating forest belts or forest-orchard belts which separate the soil-conserving crop rotations from the principal rotations are used in addition to ravine-gully plantings;

3) on weakly dissected catchments (ravine-gully density less than 0.5 km/km^2, length of overland flow greater than 700 m) - forest belts of the alley type along the main roads, usually located on watershed divides, are used together with the gully-ravine and water-regulating belts.

The water-regulating and the alley belts must be of the loose (through blowing) type on snow-drifting or of the open lattice type on windward (snow blowing) slopes. Forest belts are usually composed of rapidly growing species: poplar, birch, pine and Siberian larch. Of the species used in the second layer the most common are linden, mountain ash, apple; and of the shrubs - hazel, yellow acacia, willow, and dog rosa. The planting of the forest species are made with seedling ("agrotechnical Instruction.....", 1961).

According to the instructions of the Main Administration of Forestry and Protection of Forests at the Council of Ministers RSFSR (1961) to N.S.Kamyshev (1961), V.A.Kargov (1962) and others, the following are recommended for afforestation of eroded land near ravines and of the slopes of the ravine-gully net in the CCP: a) on exposed chalk and limestone slopes - chalk pine, ordinary oak, white birch, hazel, wartybark evonymus, and dog rosa; b) on sandy soils - ordinary pine, crimean pine, white birch and white acacia; c) on sandy loams - various types

of pines, ordinary oak, white birch, and white and yellow acacia; d) on clay formations - ordinary oak, white birch, Norway maple, little-leaf linden, European ash, apple, forest pear, hazel, wartybark evonymus, yellow acacia, and forest honeysuckle.

In accordance with the recommendation of A.S.Kozmenko (1937b) a simplified non-laborious method of planting acorns without subsequent care was used in afforesting the banks of the ravine-gully net on the territory of the Novosil'skaya Agroforest Reclamation Station. Along the edges of the south-facing banks which are subject to landslides, there were created so-called "shading" forest belts. To prevent blowing of the snow off the ridge areas one-or two-row "snow distribution" belts were planted along the contours and perpendicular to the slopes. After reaching a height of 5 m these belts increased the snow accumulation on the fields by 45%. To convert surface into subsurface runoff "water absorbing" belts were grown in the middle part of the slope.

The Novosil'skaya Agroforest Reclamation Station achieved great effectiveness in the protection of the soils from erosion by the use of meadow amelioration of slopes. So-called "settling cells" about 100 x 100 m which are meadow areas bounded with 2-3 row forest belts are not only an effective means of protecting the soil from erosion and of restoring its productivity but are also a means of obtaining an additional amount of forage on "waste land" - areas near ravines (Dukhnov and Glybin, 1961).

The reclamation value of complex protective plantings in the CCP is enormous. According to the observations of V.A.Kargov (1962) the runoff coefficients from treated and untreated catchments under the conditions of the Novosil'skaya Agroforest Reclamation Stations were

respectively 0.10 and 0.32 in 1959 and 0.38 and 0.79 in 1950. Soil erosion on the same catchment in 1960 was 0.32 and 1.38 tons/ha. respectively.

It is necessary to point out that the forest plantings existing in the CCP are often not able to absorb the principal part of surface runoff. In order to reduce the energy of surface runoff water on slopes and for direct protection of watercourses from destruction it is necessary to build various hydrotechnical structures including terraces, water-collecting ridges; water-spreading devices; flumes; chutes; stilling pools; wattle fence, brush, and stone check dams; and others (Gussak, 1940; Braude, 1958; Kobezskiy, 1959).

Terracing of slopes is widespread in many countries and particularly in the USA where it was proposed to girdle the entire continent with terraces. According to J. Stallings (1945) terracing of steep slopes (up to 10-16%) in the USA reduces water erosion 5-10 fold. As reported by R. Dickson and others (1947) there was practically no erosion during the last twenty years on terraced Texas fields.

Various types of structures in the form of chutes with troughs, apron structures, stilling basins of concrete and masonry can be used for safe disposal of water into the hydrographic net but like the terraces their construction is quite expensive. Grassed waterways are most commonly used for safe disposal of water from fields into the hydrographic net. Temporary structures made of local materials (brush, poles, wire, etc.) are used to stabilize gullies.

2. Measures Near the Reservoir

An erosion-hydrographic survey of a number of reservoirs in the Kursk and Voronezh Provinces (Frolov, 1961b), showed that their protection from erosion was poorly organized.

At the present time, because of a series of objective reasons, a complete regulation of water runoff along the three "lines of defense" is unfortunately not possible. Considering that water erosion is not uniform over the area of the catchment (Frolov, 1963) one must in employing a complex of erosion control practices on a catchment, pay principal attention to the land near the gully net and to the hydrographic land where, as is known, erosion is most severe.

To protect the surface of catchments from water erosion and to reduce the inflow of sediments into the reservoir the following measures are necessary in addition to special methods of water retention (see above).

The areas of the catchments near the drainage net with slopes greater than 4% must be excluded from the main crop rotations and must be used in soil-conserving crop rotations which include plant residues (stubble, mulch) left over the winter.

Strips along the edges not less than 20-40 m wide must be left in grass to settle out the products of water erosion.

It is very important that the lower part of the catchment immediately above the reservoir be put in grass in order to settle out the products of water erosion. Immediately around the reservoir for a distance of 40-50 m from the water line, it is necessary to plant forest shelter belts. The widths of the forest belt should be 50-100 m (Nikolaenko, 1961; Molchanov, 1962). The grass strip between the forest plantings and the surface of the reservoirs must be used for hay and must not be allowed to be grazed.

In channels (the hydrographic net) which carry large amounts of sediment, settling basins must be built

and multiple rows of brush willows alternating with grass strips 10-20 m wide must be planted across the waterways.

Ravines with considerable washing must be completely afforested. To prevent the destruction of the side-slopes of the dams it is necessary to stabilize them by sodding or planting of shrubs (willow, honeysuckle, acacia, dog rosa). The planting of tall and wide crowned trees on slopes of dams is undesirable because the roots cause seepage of water from the reservoir and the leaves fall into it and impair the quality of the drinking water.

On reservoirs with a long wave fetch where during wave action there could be bank erosion it is necessary to plant wave-breaking shrubs on the windward side below the backwater level. In individual cases where wave-breaking plantings of shrubs is impossible it is necessary to use two-row willow fences to protect the banks from destruction.

For all reservoirs used for domestic water supplies it is necessary in addition to set up a special zone of sanitary protection (Emel'yanov, 1958; Nikolaenko, 1961). For the protection of such reservoirs the Sanitary Inspection requires that the entire shore zone be forested except for a grass strip around the reservoir. In planning forest shelter belts on the banks of reservoirs, it is necessary to utilize the experience of the All-Union Agrolesoproekt Combine ("Brief Instruction for Planning Protective Forest Plantings on Banks of Reservoirs", 1957).

Thus, in conformity with the occurrence of water erosion and with conditions of forming of sediment runoff the reduction of inflow of sediment into a reservoir must be based on a combination of erosion control measures applied on the catchment and near the reservoir.

A survey of a number of small catchments in the Kursk and Voronezh Provinces showed that only a combination of administrative-economic, agrotechnical, phytomeliorative

and hydrotechnical measures on catchments is a dependable guarantee for the protection of reservoirs from silting. By the application of a combination of these measures soil erosion from catchments and silting of reservoirs such as, for instance, the Berezovaya Reservoir in the Kursk Province (Frolov, 1961b) was sharply reduced.

Conclusions

1. Soil erosion on catchments and forming of the sediment flows of small streams in the CCP depend on many physical-geographical factors: relief, climate, soil, vegetation, and others. They do, to a considerable extent, determine the state of the surface of plowed land on catchments in the Spring.

The examination and analysis of soil erosion data on runoff plots and on unit catchments in the CCP and in neighboring districts showed that water erosion from fall-plowed land and from winter crops which in the CCP occupy the main part of the catchments (45-55 and 30-35% of the entire area respectively) is about the same. Water runoff from fall-plowed land is generally 1.5-2.0 times less than from winter crops while the specific erosion on fall-plowed land with the same soils is twice that on land in winter crops. Other types of land use (stubble, long-fallow, grasses, forests) protect the soil from water erosion.

2. The pattern of crop land in the CCP has been undergoing a number of changes in recent times. These changes affect principally the summer-fall state of cultivated land. Along with an increase in row crops which are the most dangerous with respect to erosion (corn, sunflower, sugar beets), there is a general replacement of clean fallow by cropped fallow which is conducive to a reduction of water erosion during the summer.

In the CCP where during the summer-fall seasons water runoff and soil erosion occur only when at least 30-40 mm of rainfall occurs at one time and where the intensity and frequency of heavy rains are not too high, the forming of the sediment flow of small streams will as in the past be determined principally by the land use in the Springtime which remains unchanged. Therefore, the rate of water erosion will not increase.

3. The principal part of water-and sediment flow of small streams in the CCP is formed during the Spring high-water period. During the Spring-high water about 85% of the entire annual water flow and 95% of the sediment pass through the intermittent streams (ravines and gullies) of the CCP. On small streams (creeks and small rivers) with perennial flow the Spring water and sediment flows constitute about 60% of the annual. The considerable percentage of the annual water flow represented by the winter flows of intermittent and of perennial small streams (10-15%) is due to frequent winter thaws and floods. However, the sediment runoff for this period of the year does not exceed 10-15% even on small rivers. The somewhat higher (up to 20% and more) sediment flow of perennial streams during the summer period is due to channel erosion.

4. The regimes of water-and sediment flows of small streams in the CCP are identical. The regime of the Spring flows of water and of sediment is intensive and has diurnal variations.

The average rate of sediment flow of small streams in the CCP is about 1.2-2.4 tons/ha. which corresponds approximately to the erosion from the main part of the catchment obtained from observations on runoff plots.

During the transition from overland flow to channel flow, deposition (settling out) of sediments occurs on the

slopes of the ravine-gully net and gully erosion also takes place. The sharp increase in sediment flow of individual very small watercourses with catchment areas less than 2-5 km^2 is due principally to gully erosion.

The total sediment runoff from branched ravine catchments of the CCP on which gully erosion and a settling out of products of water erosion on the slopes occur is determined by the amount of sediment measured in the closing section of the main ravine or by the value of sheet erosion, because the amounts of sediment settled out on the slopes is compensated by the amount of sediment of gully origin passing through the closing section. It can be determined with the sheet erosion formula as the product of three basic values.

$$R = aWI,$$

where α is the erosion coefficient or specific soil erosion; W - the water runoff; I - mean-weighted slope of the surface of the catchment.

Values of the erosion coefficient can be obtained from erosion data for soils with different land use (Table 4). When data on land use are lacking the following empirical relationship obtained from the analysis of conditions of forming of sediment runoff can be used in determining the erosion coefficient.

$$a = k\,\frac{H\,(n + n')\,a}{\sqrt[4]{F+1}},$$

where F - catchment area, km^2; H - depth of the erosion base, km; n - ravine-gully density, km/km^2; n' - extent of gullying, km/km^2; a - extent of cultivation on the catchment, parts of 1.0; k - parameter, which accounts for the climatic, soils, and other factors of forming of sediment runoff.

5. The verification of the most common methods of computing sediment runoff from small catchments in the CCP on specific example showed that the discrepancies between computed and measured values were, in a whole series of cases, greater than ± 50-100%.

The following empirical relationships are recommended for the computation of long-term sediment runoff from small catchments and in the determination of the long-term mean annual turbidity of small streams in the CCP.

$$R_{s,v} = k \frac{H (n + n') a}{\sqrt[4]{F + 1}} WI;$$

$$R_{s,w} = 1.2k \frac{H (n + n') a}{\sqrt[4]{F + 1}} WI;$$

$$\rho_s = 1.2k \frac{H (n + n') a}{\sqrt[4]{F + 1}} I \cdot 10^3,$$

where $R_{s,v}$ and $R_{s,w}$ are values of sediment runoff, by volume (m^3) and by weight **tons**, ρ_s - mean annual turbidity, gm/m^3.

The computation of the sediment flow and of turbidity of small streams with the empirical formulas presents no particular difficulties. The principal water erosion characteristics of catchments can be obtained from large scale topographic maps. A map was constructed for the determination of the parameter k. The values of k are zonal in nature and change with regularity over the territory of the CCP from the northwest to the southeast (from 0.2-0.5 to 2.0-5.0).

The map of depth of Spring runoff constructed by K.P.Voskresenskiy (1951) for the forest-steppe and steppe zones of the European part of the USSR is recommended for the determination of water inflow. B.K.Vakhtin's (1931) formula with a correction coefficient of 1.4 is recommended for the determination of the average slope of the surface of a catchment.

The computations of mean annual turbidity of small streams with the proposed relationship gave quite satisfactory results. The average deviation from measured values being ±15.3%.

The obtained formulas for the computation of sediment flow and for the determination of the mean annual turbidity of small streams in the CCP can, in the future, be utilized also in other regions of the USSR, provided data on the geographical distribution of the parameter k are available.

6. The reduction of inflow of sediment into a reservoir must be based on a complex of administrative, economic, agrotechnical, phytomeliorative and hydrotechnical measures applied on the catchment and near the reservoir. Because soil erosion over the area of the catchment is not uniform it is necessary in applying the complex of erosion control measures to pay principal attention to areas near the drainage network and to the slopes of the hydrographic net where water erosion is most intensive.

In addition to special methods of water retention by plowing, the following measures are a necessary minimum.

Areas of the catchment near the drainage net with slopes of 4° or steeper must be excluded from the main crop rotations and must be included in the soil-conserving rotations in which cereal-legume plants and perennial grasses constitute from 50 to 60%. Plant residue (stubble, mulch) must be left over the winter.

Near edges of banks, strips not less than 20-40 m wide must be left in grass in order to settle out the products of erosion.

The slopes of the hydrographic net must be subjected to phytoamelioration.

It is necessary that the low parts of the catchments immediately above the reservoirs be put in grass and a protective forest planting.

The application of the minimum of the indicated measures and of other practices gives dependable protection of reservoirs from silting.

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Appendix 1

RESULTS OF OBSERVATIONS OF SPRING WATER RUNOFF AND OF SOIL EROSION FROM SMALL CATCHMENTS

Soils	Years of observation	Type of land use	Number of runoff plots or elementary catchments	Area, ha	Average slope, J, ‰	Water runoff, h, mm	Runoff coefficient	Sediment runoff (soil erosion) R, m	Sediment runoff (soil erosion) μ, мк	Average turbidity g/m³	Erosion coefficient, α	Author and method of determining soil erosion
Center of European USSR, Tula Province												
Gray forest-steppe loam . . .	1941	Fall plowed	2	0.38	70	56	0.44	16.80	3680	78900	0.94	A. S. Shamshin (1961); from volumes of rills and turbidity.
Same	1941	Winter crop	2	0.38	70	74	0.53	1.20	260	4270	0.050	
"	1941	Perennial grasses	2	0.38	70	118	0.72	0.92	210	2170	0.025	
Pridesnyanskaya Upland, Chernigov Province												
Podzolized chernozem	1947—1956	•F.p. up and down	—	—	—	—	0.45	—	375	—	—	A. I. Gonchar (1962).
Same	1947—1956	F.p. across	—	—	—	—	0.28	—	150	—	—	
"	1947—1956	F.p. (intermed.)	—	—	—	—	0.36	—	262	—	—	
"	1947—1956	Winter crop	—	—	—	—	0.54	—	33	—	—	
"	1947—1956	Stubble	—	—	—	—	0.52	—	25	—	—	
"	1947—1956	Fallow, grasses	—	—	—	—	0.62	—	0	—	—	
Kursk Station Institute of Geography Acad. of Sci. USSR												
Leached chernozem	1959	F.p. up and down	1	0.45	30	31	0.65	0.46	85	3300	0.091	A. M. Green (1963) from turbidity.
Same	1959	F.p. across	1	0.45	30	25	0.56	0.28	52	2480	0.069	
"	1959	F.p. (intermed.)	2	0.45	30	28	0.61	0.37	68	2800	0.081	
"	1959	Winter crop	2	0.45	32	36	0.77	0.65	120	4000	0.104	
"	1959	Stubble	1	0.45	30	62	0.95	0.11	21	400	0.011	
"	1959	Virg. land grazed	1	0.38	32	18	0.53	0.004	0.8	60	0.001	
Dark gray forest	1959	Perennial grasses	1	0.45	40	60	0.74	0.032	5.8	120	0.002	
Gray forest, podzolized	1959	Field after potato harvest	1	0.45	50	71	0.90	1.94	359	6060	0.101	

Приложение 1 (*продолжение*)

	Годы наблюдений	Тип сельскохозяйственного поля и угодья	Число стоковых площадок или элементарных водосборов	Площадь, га	Средний уклон J, ‰	Сток воды h, мм	Коэффициент стока	Сток наносов (смыв почвы) R, m	Сток наносов (смыв почвы) μ, мк	Средняя мутность ρ, г/м³	Эрозионный коэффициент, α	Автор и метод определения стока наносов (смыва почвы)
Gray forest, podzolized . . .	1959	Same with forest belt	1	0.54	50	14	0.14	0.059	9.2	780	0.002	A. M. Green (1963) from turbidity.
Leached chernozem	1960	F.p. up and down	1	0.45	35	62	0.53	0.19	35	680	0.016	
Same	1960	F.p. across	1	0.45	33	55	0.48	0.28	52	1140	0.029	
"	1960	F.p. (intermed.)	2	0.45	34	58	0.50	0.24	44	920	0.022	
Gray forest, podzolized . . .	1960	Winter crop	1	0.45	50	192	0.98	2.00	370	2320	0.039	
Same	1960	Same with forest belt	1	0.54	50	111	0.64	0.20	31	330	0.006	
Leached chernozem	1960	Stubble	1	0.45	33	113	0.84	0.049	9.1	90	0.002	
Same	1960	Virg.land grazed	1	0.38	32	90	0.66	0.049	11	140	0.004	
"	1959—1960	F.p. up and down					0.59				0.054	
"	1959—1960	F.p. across					0.52				0.049	
"	1959—1960	F.p. (intermed.)					0.56				0.052	
Same and podzolized gray forest . . .	1959—1960	Winter crop					0.80				0.072	
Leached chernozem	1959—1960	Stubble					0.90				0.006	
Same	1959—1960	Virgin land					0.60				0.002	
KZOMS (KURSK ZONAL EXPER. RECLAM. STA.) KURSK PROVINCE												
Deep chernozem . .	1958	Special methods of fall plowing	6	0.98	25	27	0.56	0.12	10	440	0.015	V. Ya. Frolov (1961b); from turbidity.
DOKUCHAEV AGRIC. INST. OF THE CENTRAL CHERNOZEM BELT, VORONEZH PROVINCE												
Ordinary chernozem	1958—1960	Ordinary F.p.	1	0.37	46	3.3	0.090	1.15	258	94000	1.700	P. S. Tregubov (1961); from volumes of rills.
Same	1958—1960	F.p. with basin listing	1	0.36	42	6.5	0.081	0.36	83	15400	0.304	

Приложение 1 (*продолжение*)

	Годы наблюдений	Тип сельскохозяйственного поля и угодья	Число стоковых площадок или элементарных водосборов	Площадь, га	Средний уклон J, ‰	Сток воды h, мм	Коэффициент стока	Сток наносов (смыв почвы) R, т	Сток наносов (смыв почвы) ρ, мк	Средняя мутность ρ, г/м³	Эрозионный коэффициент, α	Автор и метод определения стока наносов (смыва почвы)
Ordinary chernozem	1958—1960	F.p. with subsoiling.	1	0.38	44	7.9	0.083	2.51	550	83600	1.580	P. S. Tregubov (1961); from volumes of rills.
Same	1958—1960	Plowed without mold-board.	1	0.36	41	2.6	0.051	0	0	0	0	
"	1958—1960	Stubble.	1	0.37	46	47.6	0.50	4.44	1000	25200	0.456	
		Nansen Sovkhoz Saratov Province.										
Ordinary chernozem	1952	Fall plowing.	1	0.2	30	14.8	—	0.010	4.1	340	0.092	I. A. Kuznik (1961) from turbidity.
Same	1952	Winter crop.	1	59.0	31	48	—	2.74	4.0	100	0.027	
"	1952	2nd year alfalfa.	1	5.27	—	14	—	0	0	0	0	
"	1952	Grass mixture (alf. & ryegrass)	1	11.8	14	37	—	0.11	1.0	25	0.002	
"	1952	Perennial grasses (average).	2								0.001	
	1953	Fall plowed.	1	2.0	35	82.5	—	0.91	37.9	550	0.131	
"	1953	Grass mixture (alf. & ryegrass)	1	53.2	—	111	—	0	0	0	0	
"	1953	1st year grass mixture with nurse crop.	1	59.0	30	34	—	2.32	3	120	0.029	
"	1953	Perennial grasses (average).	2								0.014	
"	1954	Fall plowed.	1	1.0	26	12.8	—	0.20	16.7	1560	0.050	
"	1954	Winter crop.	1	18.0	30	54	—	10.40	48	1070	0.030	
"	1954	Grass mixture (alf. & ryegrass)	1	10.1	26	26	—	0.029	0.2	10	0.0003	
"	1955	Fall plowed.	1	18.0	20	49.0	—	10.05	46.4	1140	0.047	
"	1955	Stubble.	1	2.0	16	31	—	0.018	1	30	0.002	

Приложение 1 (*продолжение*)

	Годы наблюдений	Тип сельскохозяйственного поля и угодья	Число стоковых площадок или элементарных водосборов	Площадь, га	Средний уклон J, °, ‰	Сток воды h, мм	Коэффициент стока	Сток наносов (смыв почвы) R, m	Сток наносов (смыв почвы) μ, мк	Средняя мутность ρ, г/м³	Эрозионный коэффициент, α	Автор и метод определения стока наносов (смыва почвы)
Ordinary chernozem	1955	Mixed grasses 3rd year.	1	85.0	10	96	—	9.79	10	120	0.016	I. A. Kuznik (1961); from turbidity.
Same	1952—1955	Fall plowed.	4								0.080	
"	1952, 1954	Winter crop.	2								0.028	
"	1955	Stubble.	1								0.002	
"	1952—1955	Perennial grasses	6								0.006	
Kinel'skaya Station of the Kuybyshev Agric. Inst.												
Ordinary chernozem	1952	Fall plowed.	1	1460.0	8	15	—	52.50	3	240	0.025	I. A. Kuznik (1961); from turbidity.
Same	1954	"	1	1.0	35	13	—	0.20	17	1520	0.037	
"	1954	Grass mixture.	1	10.1	22	3	—	0.029	0.2	100	0.003	
"	1955	Fall plowed.	1	18.0	15	49	—	10.05	46	1140	0.063	
"	1955	Long fallow.	1	85.0	16	96	—	6.94	7	90	0.005	
"	1956	Fall plowed.	1	18.0	15	54	—	13.20	61	1360	0.075	
"	1956	Winter crop.	1	6.5	19	137	—	0.98	13	110	0.005	
"	1956	Stubble.	1	24.0	34	61	—	12.20	42	830	0.020	
"	1958	Fall plowed.	1	24.0	25	20	—	11.50	40	2400	0.080	
"	1952, 1954, 1955, 1956, 1958	"	5								0.056	
"	1956	Fall plowed.	1								0.005	
"	1956	Stubble.	1								0.020	
"	1954, 1955	Perennial grasses and fallow.	2								0.004	
Gusel'skaya Station, Saratov Province												
Southern chernozem	1953	Fall plowed.	1	3.7	50	6	—	1.88	42	850	0.140	I. A. Kuznik (1961); from turbidity.
Same	1953	"	1	1.2	29	20	—	1.22	85	5080	0.147	
"	1953	F.p. (average)	2								0.144	

Приложение 1 (*продолжение*)

	Годы наблюдений	Тип сельскохозяйственного поля и угодья	Число стоковых площадок или элементарных водосборов	Площадь, га	Средний уклон J, ‰	Сток воды h, мм	Коэффициент стока	Сток наносов (смыв почвы) R, т	Сток наносов (смыв почвы) μ, мк	Средняя мутность ρ, г/м³	Эрозионный коэффициент, α	Автор и метод определения стока наносов (смыва почвы)
"	1953	Winter crop.	1	1.23	40	20	—	0.17	12	690	0.015	I. A. Kuznik (1961); from turbidity.
"	1955	Fall plowed.	1	18.0	50	42	—	38.94	180	5150	0.086	
"	1955	Winter crop.	1	1.2	—	90	—	0.080	6	740	0.030	
"	1953, 1955	Fall plowed.	3								0.115	
"	1953, 1955	Winter crop.	2								0.022	
Tolstovskaya Station, Kolkhoz "Komsomoletz" Saratov Province.												
Dark chestnut soils	1938	Fall plowed.	1	140	40	15	—	25.16	15	1200	0.25	I. A. Kuznik (1961); from turbidity.
Same	1953	"	1	140	9	7	—	4.21	25	430	0.40	
"	1955	"	1	320	14	33	—	135.70	35	1290	0.76	
"	1938, 1953, 1955	F.p. (intermed.)	3								0.47	
Engel'skaya Station, Saratov Province												
Dark chestnut soils	1951	Fall plowed.	1	2.0	18	60	—	0.38	16	3160	0.15	I. A. Kuznik (1961) from turbidity.
Same	1955	Winter crop.	1	2.38	35	82	—	0.043	2	20	0.001	
Saratov Province, Ershov District, XVIII Party Congress Kolkhoz												
Dark chestnut soils	1953	F.p. up & down.	1	0.75	26	9.1	0.11	0.057	6.3	840	0.027	G. V. Nazarov (1958); from turbidity.
Same	1953	F.p. across	1	0.75	24	0.13	0.002	0.0001	0.01	100	0.003	
"	1953	F.p. (intermed.)	2								0.015	
"	1953	Long fallow	1	0.75	20	118	0.98	0.070	7.8	80	0.030	
"	1954	F.p. across	1	0.75	24	0.8	0.30	0.0004	0.04	70	0.002	
"	1954	Stubble	1	0.75	26	22	0.30	0.020	2.2	120	0.004	

Приложение 1 (*продолжение*)

	Годы наблюдений	Тип сельскохозяйственного поля и угодья	Число стоковых площадок или элементарных водосборов	Площадь, га	Средний уклон J, ‰	Сток воды h, мм	Коэффициент стока	Сток наносов (смыв почвы) R, m	Сток наносов (смыв почвы) ρ, мк	Средняя мутность ρ, г/м³	Эрозионный коэффициент, α	Автор и метод определения стока наносов (смыва почвы)
"	1954	Long fallow.	1	0.10	26	18	0.27	0.0022	1.8	120	0.004	
"	1955	F.p. up & down	1	1.50	22	45	0.48	0.43	23.8	640	0.024	
"	1955	F.p. across	1	1.05	26	15	0.26	0.18	14.6	1140	0.037	
"	1955	F.p. (intermed.)	2								0.030	
"	1955	Stubble	1	0.16	18	70	0.65	0.036	18.8	320	0.015	
"	1955	1st year perennial grasses.	1	0.75	26	89	0.91	0.18	19.9	270	0.009	
"	1955	Long fallow.	1	0.10	26	72	0.72	0.013	10.7	180	0.006	
"	1955	Perennial grasses & fallow (avg.)	2								0.008	
"	1956	F.p. up & down.	1	0.75	25	3.1	0.024	0.0018	0.2	80	0.003	
"	1956	F.p. across.	1	0.30	28	1.7	0.011	0.0010	0.3	200	0.006	G. V. Nazarov (1958); from turbidity.
"	1956	F.p. (intermed.)	2								0.004	
"	1956	Stubble.	1	0.10	34	21	0.43	0.0089	7.4	420	0.010	
"	1956	2nd year perennial grasses.	1	0.75	26	98	0.75	0.16	17.6	220	0.007	
"	1956	Long fallow.	1	0.10	26	66	0.70	0.0062	5.2	90	0.003	
"	1956	Perennial grasses & fallow (avg.)	2								0.005	
"	1953—1956	F.p. up & down.	3								0.018	
"	1953—1956	F.p. across.	4								0.012	
"	1953—1956	F.p. (intermed.)	7								0.015	
"	1954—1956	Stubble.	3								0.010	
"	1953—1956	Perennial grasses and fallow.	6								0.010	

Appendix 2

Parameter k Obtained from Data on the Sediment Load of Small Streams and from Silting of Ponds and of Small Reservoirs.

	Water body	Location	Catchment soils	Catchment area F, км^2	Mean weighted slope of catchment I, ‰	Erosion-geomorphic coefficient (for k = 1.0)	Annual water runoff: h, мм	Annual water runoff: W, 10^6 м^3	Annual sediment runoff: μ, мк, Computed	Annual sediment runoff: μ, мк, Measured	Annual sediment runoff: $R_{н,о}$, 10^3 м^3, Computed	Annual sediment runoff: $R_{н,о}$, 10^3 м^3, Measured	Parameter k	Source of data on sediment flow and silting
	Small Streams													
1	Karachan - Aleshki.	Voronezh Prov. Khoper River Basin.	Ordinary chernozems	565	27	0.0068	96	54.2	18	51	9.95	28.8	2.9	
2	Khava - Il'inovka.	Voronezh Prov. Don River headwaters.	Deep chernozems	426	27	0.0059	96	40.9	15	20	6.52	8.52	1.3	
3	Kosta - Glazovo.	Desna River Basin.	Sod-podzolic and gray forest.	139	46	0.0056	170	23.6	44	9	6.08	1.25	0.2	
4	Bobrovnik - Pisarevo.	Same.	Same.	99.6	44	0.024	126	12.5	133	24	13.2	2.39	0.2	Hydrologic yearbooks.
5	Orlitsa - Bol'shoy.	Orel Prov. Oka Riv. Basin.	Gray forest.	96.0	72	0.027	128	12.3	248	8	23.9	0.77	0.03	
6	Kur - Kazatskaya	Kursk Prov. Tuskar' Riv. Basin.	Deep chernozems	66.0	56	0.013	100	6.60	73	72	4.80	4.75	1.0	
7	Kleshnya - Rakitno.	Voronezh Prov. Elan' River Basin.	Same.	58.0	24	0.0088	110	6.38	23	14	1.35	0.81	0.6	
8	Merech'e - Alekseevskiy.	Kursk Prov. Seym Riv. Basin.	"	8.69	68	0.035	75	0.65	178	71	1.55	0.62	0.4	V. Ya. Frolov (1963).
9	Raychik - Lukashevka.	Same.	"	6.49	75	0.067	75	0.49	377	212	2.46	1.38	0.6	

Приложение 2 (*продолжение*)

	Водный объект	Местоположение	Почва водосбора	Площадь водосбора F, км²	Средневзвешенный уклон поверхности водосбора I, ‰	Эрозионно-геоморфологический коэффициент (при $k = 1.0$)	Сток воды за год: h, мм	Сток воды за год: W, 10^6 м³	Сток наносов за год: μ, мк, расчетный	Сток наносов за год: μ, мк, фактический	Сток наносов за год: $R_{н,о}$, 10^3 м³, расчетный	Сток наносов за год: $R_{н,о}$, 10^3 м³, фактический	Параметр k	Источник получения данных о стоке наносов и заилении водоемов
10	L. Barsuk - gaging sta.	Voronezh Prov. Nizhnedevitskaya Runoff Station.	Deep chernozems.	10.7	62	0.034	62	0.66	131	90	1.39	0.96	0.7	Data of the Nizhnedevitskaya Runoff Station.
11	L. Medvezhiy-gaging sta.	Same.	Same.	2.55	46	0.046	58	0.15	123	81	0.32	0.21	0.7	
12	L. Ivkin-gaging sta.	"	"	0.55	78	0.086	50	0.027	335	285	0.18	0.16	0.9	
13	L. Churakov - gaging sta.	"	"	1.56	78	0.098	92	0.14	703	1150	1.07	1.79	1.7	
	Ponds and Reservoirs													
14	Borshchenskoe.	Kursk Prov. Ivaninskiy Dist.	Deep chernozems.	48.0	75	0.040	74	3.55	222	172	10.6	8.22	0.8	G. V. Lopatin (1961).
15	Uspenskoe.	Same.	Same.	33.2	68	0.039	75	2.49	199	187	6.60	6.20	0.9	G. V. Lopatin (1963).
16	Malaya Kulikovka.	Orel Prov.- Orel Dist.	Dark gray forest.	18.8	43	0.023	70	1.34	69	36	1.32	0.67	0.5	L. V. Yakovleva (this collection).
17	Ol'shanskie Vyselki.	Same.	Same.	3.43	70	0.039	70	0.24	192	90	0.65	0.31	0.5	
18	Pervyy Voin.	Orel Prov. Mtsensk Dist.	"	20.4	35	0.038	70	1.43	93	45	1.90	0.92	0.5	
19	Nelidovskiy.	Kursk Prov. B.Soldatskiy Dist.	Deep chernozems.	11.2	75	0.052	69	0.77	269	131	3.00	1.47	0.5	I. N. Sorokin and L. V. Yakovleva (1961).
20	Durnovskiy.	Kursk Prov. Ivaninskiy Dist.	Same.	15.7	52	0.038	73	1.15	144	124	2.27	1.94	0.9	
21	Lyubimovskiy.	Kursk Prov. Korenevskiy Dist.	Podzolized chernozem.	19.8	58	0.024	67	1.33	93	28	1.85	0.56	0.3	

Приложение 2 (*продолжение*)

	Водный объект	Местоположение	Почва водосбора	Площадь водосбора F, км²	Средневзвешенный уклон поверхности водосбора I, ‰	Эрозионно-геоморфологический коэффициент (при $k = 1.0$)	Сток воды за год: h, мм	Сток воды за год: W, 10^6 м³	Сток наносов за год: ρ, мк, расчетный	Сток наносов за год: ρ, мк, фактический	Сток наносов за год: $R_{н,о}$, 10^3 м³, расчетный	Сток наносов за год: $R_{н,о}$, 10^3 м³, фактический	Параметр k	Источник получения данных о стоке наносов и заилении водоемов
22	Murynovskiy.	Same.	Same.	5.90	87	0.042	65	0.38	237	95	1.39	0.56	0.4	I. N. Sorokin & L. V. Yakovleva (1961).
23	Viktorovskiy.	"	Deep chernozems	5.20	66	0.025	63	0.33	104	81	0.54	0.42	0.8	
24	Artyukhovskiy.	Kursk Prov. Lenin Dist.	Same.	6.50	32	0.015	71	0.46	34	37	0.22	0.24	1.1	
25	Kondratovskiy.	Kursk Prov. Belovskiy Dist.	Podzolized chernozem.	8.35	91	0.037	66	0.55	222	78	1.85	0.65	0.4	
26	Bashkatovskiy.	Kursk Prov. Oboyanskiy Dist.	Same.	4.00	128	0.056	65	0.26	466	285	1.86	1.14	0.6	
27	Vyshnederevenskiy	Kursk Prov. L'govskiy Dist.	"	1.40	60	0.026	70	0.098	109	72	0.15	0.10	0.7	
28	Mikhinskiy.	Voronezh Prov. Talovskiy Dist.	Ordinary chernozems.	2.34	14	0.0076	60	0.14	6.4	90	0.015	0.21	14.0	I. P. Sukharev (1961).
29	Starodubovskiy.	Same.	Same.	22.7	23	0.0058	62	1.41	8.3	46	0.19	1.05	5.5	
30	Nizhnekamenskiy.	"	"	42.5	28	0.018	64	2.72	32	90	1.37	3.82	2.8	
31	Gorovskiy.	Volgograd Prov. Buzuluk Riv. Basin.	Ordinary & southern chernozems.	0.28	49	0.013	54	0.015	34	250	0.095	0.070	7.4	I. N. Sorokin (1960).
32	Pletnyak.	Same.	Same.	0.93	57	0.014	54	0.050	40	226	0.037	0.21	5.7	Same
33	Chukunovskiy.	"	"	2.05	28	0.0088	54	0.11	13	93	0.027	0.19	7.0	
34	Titovskiy.	"	"	1.06	52	0.017	53	0.056	47	425	0.050	0.45	9.0	
35	Koruninskiy.	"	"	0.51	43	0.023	54	0.028	53	274	0.027	0.14	5.2	
36	Lazarev.	"	"	0.58	26	0.011	53	0.031	15	172	0.009	0.10	11.1	
37	Verkhekulakovskiy.	Volgograd Prov. Medveditsa Riv. Basin.	"	0.41	42	0.0075	54	0.022	17	102	0.007	0.042	6.0	
38	Karagach.	Same.	"	0.69	48	0.016	54	0.037	41	217	0.028	0.15	5.4	

R e m a r k s. 1. Volume-weight of sediment of all stream assumed = 1.2 T/m^3 and the measured weight of sediments was correspondingly reduced 1.2 times. 2. For all ponds and reservoirs the measured sediment load was determined from the silted volume and was reduced 1.7 times taking into account the ratio of the volume-weights of sediments (1.2 T/m^3) to that of their deposits (0.7 T/m^3).

A p p e n d i x 3

WATER AND SEDIMENT DISCHARGES AND EROSION COEFFICIENT (AFTER B. V. POLYAKOV) OF THE PRINCIPAL RIVERS OF THE CENTRAL CHERNOZEM PROVINCES

No.No. on the map	River, point	Years of observation	Number of years of record	Catchment area, km^2	Mean annual weighted longitud. slope of stream, ‰	Average for the period of record of sediment runoff			
						Sediment discharge kg/sec.	Water discharge m^3/sec.	Turbidity g/m^3	Polyakov's erosion coefficient
	V o l g a B a s i n								
I	Oka - Orel	1949—1952	4	4790	0.55	6.24	20.7	301	1.3
II	Oka - Kaluga	1935—1940, 1949—1959	17	54900	0.14	38.7	264	147	1.2
III	Zusha - Mtsensk.	1950—1959	10	6000	0.27	4.50	28.3	159	1.0
	D n e p r B a s i n								
IV	Desna - Bryansk	1938—1940, 1950—1959	13	12400	0.10	2.48	75.3	33.0	0.3
V	Seym - Ryl'sk	1949—1959	11	18100	0.10	2.18	75.5	28.9	0.3
VI	Seym - Mutino	1933—1935, 1938, 1953—1959	11	25600	0.07	2.48	93.5	26.5	0.3
VII	Tuskar' - Kursk	1945, 1948—1951, 1953—1959	12	2500	0.48	1.57	9.73	161	0.7
VIII	Svapa - Staryy Gorod . . .	1950—1959	10	3600	0.30	1.58	16.7	94.6	0.5
IX	Psel - Zapsel'e	1932—1933, 1935, 1951—1959	12	21800	0.14	2.76	48.8	56.6	0.5
	D o n B a s i n								
X	Don - St. Kazanskaya . . .	1931—1932, 1934—1940, 1946—1959	23	102000	0.09	44.2	325	136	1.4
XI	Sosna - Elets	1950—1959	10	16300	0.26	42.8	71.9	595	3.7
XII	Voronezh - Voronezh . . .	1951—1953	3	21100	0.10	6.76	90.6	74.6	0.8
XIII	Khoper - Balashov	1947—1952, 1955—1959	11	14300	0.16	4.20	45.3	92.7	0.7
XIV	Khoper - Novokhopsk . . .	1949—1959	11	34800	0.12	13.1	104	126	1.1
XV	Khoper - Besplemyanov-skiy	1935—1959	25	44900	0.12	8.00	120	66.7	0.6
XVI	Khoper - Dundukovskiy . .	1936—1959	24	60600	0.11	12.8	137	93.4	0.9
XVII	Vorona - Chutanovka . . .	1946—1959	14	5560	0.33	2.60	19.1	136	0.7
XVIII	Buzuluk - B. Luk'yanov-skiy	1936—1959	24	9220	0.19	2.95	15.8	187	1.4
XIX	Medveditsa - Lysye Gory .	1939, 1941, 1949—1953	7	7610	0.22	2.14	16.3	131	0.9
XX	Medveditsa - Archedin-skiy	1931—1959	29	33700	0.18	14.8	65.0	228	1.7

R e m a r k. Catchment areas and mean weighted longitudinal slopes of streams are taken from "Al'bom..." (1955).

L. V. YAKOVLEVA

CHARACTERISTICS OF SILTING OF SMALL RESERVOIRS OF THE CENTRAL CHERNOZEM PROVINCES AND COMPUTATION OF DENSITY OF BOTTOM DEPOSITS

The total number of small artificial reservoirs on the territory of the Central Chernozem Provinces (CCP) is quite considerable - about seven thousand (Pashnev, 1960). The ponds in this territory are of great economic importance. They are used as sources of water for irrigation, for stock water, and in meeting various needs of the local population. In recent years the use of ponds for fish cultire is increasing.

The study of silting of small reservoirs in the CCP was carried out by the Laboratory of Limnology during 1956-1960. During this period data were collected for 44 reservoirs. Of the investigated number 32 reservoirs lie in the southwestern part of the Kursk Province in the inter-river area of the Seym and Psel Rivers; four reservoirs are in the basin of the upper reaches of the Oka River and lie in the Orlovskiy, Mtsenskiy and Kromskiy Districts of the Orel Province; eight of the reservoirs are in the Talovskiy District of the Voronezh Province. The silting characteristics of three reservoirs located on small rivers in the basin of the upper reaches of the Vorskla River in the Kursk Province are given in K.P.Voskresenskiy's (1956) paper. In 1953 I.P.Sukharev measured the thickness of the silt deposits in a number of reservoirs in the Talovskiy District of the Voronezh Province (1958, 1961). Data on the silting of five reservoirs in the Nizhne-Vedugskiy, Ol'khovatskiy and Rososhanskiy Districts of the Voronezh Province are found in the article of V.E.Vedenyapin (1961). The locations of ponds in the CCP which were investigated with respect to silting are shown in Figure 1.

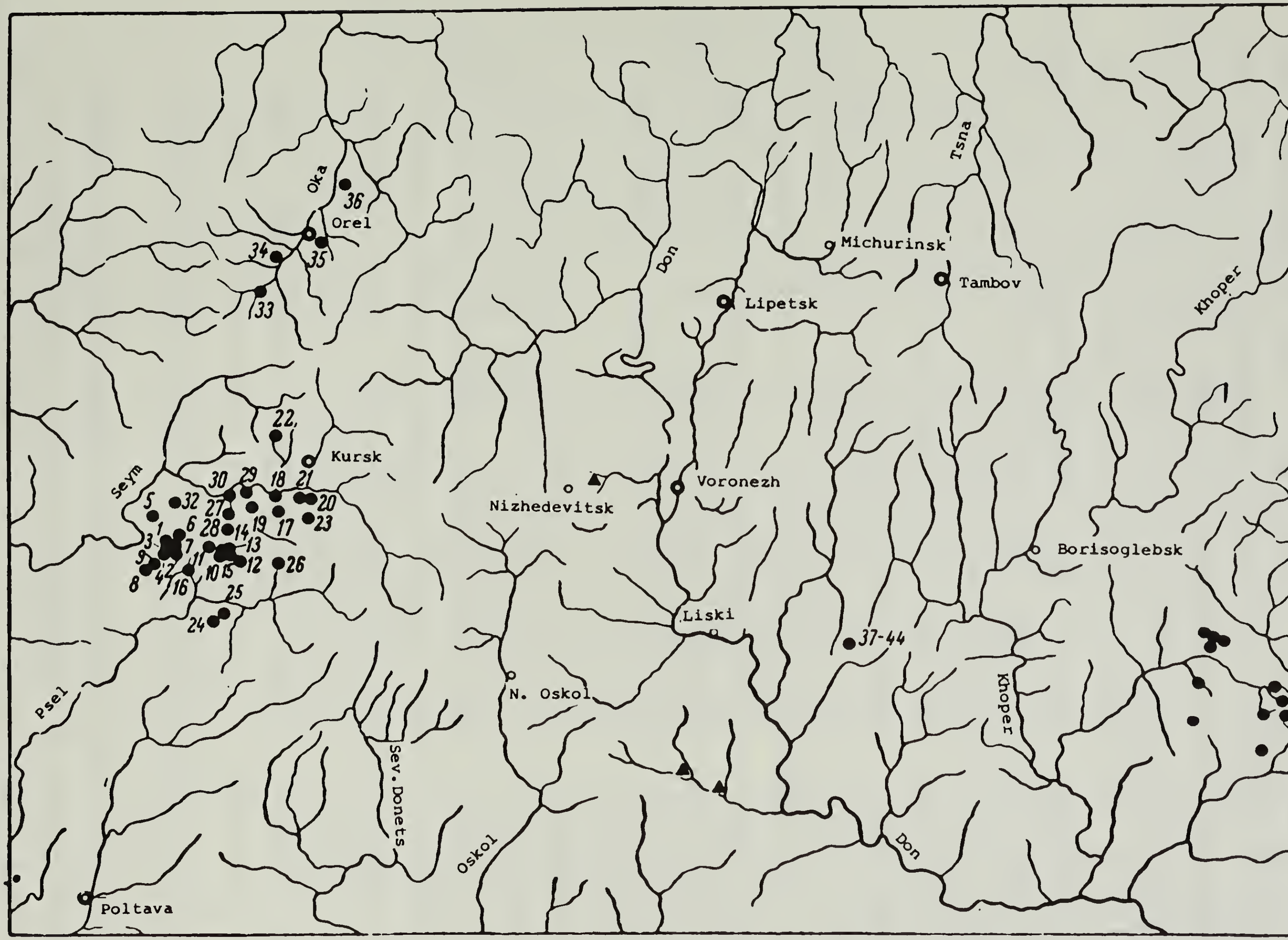

FIG. 1. DISTRIBUTION OF PONDS ON THE TERRITORY OF THE CENTRAL CHERNOZEM PROVINCES

Dots indicate ponds investigated by the Limnological Laboratory, Acad. of Sci. USSR; triangles indicate ponds after V. E. Vedenyapin.

The results of the sedimentation survey of reservoirs in the inter-river area between the Seym and Psel Rivers are presented in the paper by Sorokin and Yakovleva,(1961).

C h a r a c t e r i s t i c s o f s i l t i n g o f r e s e r v o i r s. The data of the investigations showed that the rate of silting of reservoirs in the CCP varies widely and in many cases is quite high. Thus, for ponds #17, 24, 28, and 30 (Table 1) the reduction in capacity (from the initial capacity of the ponds) due to silting is 2-3% per year, i.e., these ponds will be completely silted in 30-50 years. For 40% of the ponds surveyed in the southwest of the Kursk Province and in the Orel and Voronezh Provinces the rate of silting is close to or greater than 1% per year. This means that in 30-40 years all of these reservoirs will have largely lost their water regulating and water economy value. It is therefore necessary to take active steps now to protect them from silting. Among the surveyed ponds there are some in which the percent of silting was practically zero. These are ponds #23 and 31.

The rate of silting is determined by sheet erosion on the catchments of the reservoir. Pond #31 is located in the V.V.Alekhin Central Chernozem Reservation on a virgin steppe. There is practically no sheet erosion on the catchment area of this pond and the pond is not being silted. 16% of the catchment area of pond #23 including the slopes and bottoms of the ravines immediately above the ponds are forested. Therefore, the products of water erosion do not reach the reservoir which is practically not being silted.

The majority of the surveyed reservoirs are steppe ponds with cultivated catchment areas. The extent of silting is determined by the characteristics of the catchment basin. The most important of these characteristics are the slope of the catchment basin, the dissection by the

Table 1

COMPUTATION OF TURBIDITY AND OF THE RATE OF SEDIMENT RUNOFF OF SMALL WATERCOURSES FROM DATA ON SILTING OF RESERVOIRS ON THE TERRITORY OF CENTRAL CHERNOZEM PROVINCES.

Pond No.	Volume of silting, 10^3 m^3	Catchment area, km^2	Age of pond, years	Initial capacity, 10^3 m^3	% silted	% of silting per year.	Volume weight, g/cm^3	Volume of silting 10^3 T	Volume of silting, per year, 10^3 T.	Water regulation capacity, %	Annual sediment inflow, 10^3T	Sediment runoff rate, T/ha per year
1	15.9	7.5	8	196	8.1	1.01	0.90	14.3	1.79	0.39	1.83	2.44
2	10.3	6.4	8	268	3.8	0.48	0.70	7.21	0.90	0.66	0.91	1.42
3	33.5	21.4	9	346	9.7	1.08	0.85	28.5	3.17	0.24	3.30	1.54
4	8.57	19.8	9	607	1.4	0.16	0.85	7.28	0.81	0.46	0.83	0.42
5	5.20	7.9	9	72	7.2	0.80	0.85	4.42	0.49	0.13	0.54	0.68
6	9.16	3.7	8	107	8.6	1.08	0.85	7.79	0.97	0.44	0.99	2.67
7	7.70	5.9	8	96	8.0	1.00	(0.50)	3.85	0.48	0.25	0.50	0.84
8	12.8	3.5	43	82	15.5	0.36	(0.50)	6.40	0.15	0.36	0.15	0.42
9	5.06	5.2	7	142	3.4	0.49	0.65	3.29	0.47	0.43	0.48	0.92
10	4.15	3.7	9	81	5.1	0.57	0.60	2.49	0.28	0.33	0.29	0.78
11	7.02	3.5	8	299	2.3	0.27	0.70	4.91	0.61	1.29	0.62	1.76
12	33.4	10.1	8	683	4.9	0.61	0.75	25.0	3.12	1.02	3.15	3.12
13	10.3	5.7	7	103	9.1	1.30	0.65	6.70	0.96	0.27	0.99	1.73
14	2.57	8.8	8	85	3.0	0.38	(0.70)	11.8	0.22	0.15	0.24	0.27
15	8.35	7.6	8	160	5.2	0.65	0.50	4.18	0.52	0.32	0.53	0.69
16	4.16	11.6	9	95	4.4	0.49	0.70	2.91	0.32	0.13	0.35	0.31
17	7.50	15.7	6	62	12.2	2.03	0.65	4.88	0.81	0.06	0.99	0.63
18	11.6	16.7	8	361	3.2	0.40	0.65	7.54	0.94	0.30	0.97	0.58
19	2.85	6.50	7	50	5.7	0.81	0.90	2.56	0.37	0.11	0.41	0.64
20	8.00	6.75	31	36	21.9	0.71	0.70	5.60	0.18	0.07	0.21	0.32
21	11.6	21.0	10	103	11.3	1.13	0.60	6.96	0.70	0.06	0.85	0.40
22	7.88	9.45	60	50	15.8	0.26	0.55	4.33	0.07	0.07	0.08	0.08
23	0.00	1.29	5	7.2	0.0	0.00	—	0.00	0.00	0.07	0.00	0.00
24	7.79	8.35	7	60	12.9	1.84	0.60	4.67	0.67	0.11	0.74	0.89
25	12.4	33.7	7	196	6.3	0.90	0.55	6.82	0.97	0.09	1.10	0.33
26	13.5	4.00	7	264	5.1	0.73	0.70	9.45	1.35	1.00	1.36	3.41
27	103.8	36.7	9	948	10.9	1.21	0.71	73.7	8.19	0.36	8.36	2.55
28	12.2	11.2	6	72	16.9	2.82	(0.70)	8.54	1.42	0.09	1.61	1.44
29	69.1	33.2	6	2493	2.8	0.47	(0.60)	41.5	6.91	1.04	6.98	2.10
30	16.5	14.0	5	80	17.1	3.42	0.70	11.6	2.32	0.10	2.61	1.83
31	0.00	1.22	4	20	0.0	0.00	—	0.00	0.00	0.28	0.00	0.00
32	4.86	1.40	28	22.4	21.7	0.78	0.80	3.89	0.14	0.23	0.15	1.04
33	14.2	2.75	6	275	5.16	0.86	0.95	13.5	2.25	1.05	2.25	8.18
34	4.22	3.43	8	77.0	5.47	0.68	0.85	3.58	0.45	0.23	0.46	1.34
35	9.08	18.8	8	309	2.94	0.37	0.70	6.35	0.79	0.16	0.84	0.45
36	12.5	20.4	8	328	3.81	0.48	0.70	8.75	1.09	0.15	1.17	0.57
37	2.48	—	65									
38	1.37	—	65									
39	9.63		65	24.1	40.0	0.62	0.75	7.23	0.10			
40	8.11	} 9.40	12	96.1 } 171.0	8.40	0.70	0.75	6.08	0.51 } 0.99	0.28	1.02	1.08
41	5.37		12	50.4	10.6	0.88	0.85	4.57	0.38			
42	8.38	} 22.7	12	73.4	11.4	0.94	0.70	5.87	0.49 } 1.85	0.26	1.91	0.84
43	23.3		12	323	7.20	0.60	0.70	16.3	1.36			
44	14.8	2.34	66	74.8	19.8	0.33	0.60	8.88	0.13	0.48	0.13	0.56

R e m a r k s. 1. Normals of annual water runoff determined from K.P. Voskresenskiy's (1951) map. 2. Annual sediment inflow was computed taking into account the sediment retention capacity of reservoirs after N.I. Drozd (1961). 3. Volume-weight of deposits in reservoirs was taken from direct measurements.

ravine-gully net, the depth of the local erosion base and by land use.

The rate of silting depends on the trap efficiency of the reservoir. Ponds designed for complete retention of Spring melt waters store all of the material entering into them from the catchment area. There are relatively few such ponds - Nos. 11, 12, 26, 29 and 33. In all the other ponds the excess water in the Spring is discharged downstream through spillway channels or through siphons. Along with the excess water, part of the suspended material, the fine silt, is wasted downstream. Thus, other conditions being the same, the rate of silting of such reservoirs is somewhat lower than that of reservoirs designed for complete retention of runoff water. However, as shown by special investigations (Brune, 1953; Drozd, 1961) the trap efficiency of the reservoirs is substantial even when the water-regulating capacities are very small. Reservoirs are therefore natural settling basins for the products of water erosion.

The annual inflow of sediment and the rates (tons/ha/year of sediment runoff of small streams based on data of silting of ponds with the transitory sediment taken into account, are calculated in Table 1. The trap efficiency and the transitory part of the sediment were determined from the ratio of the pond capacity to the volume of annual inflow of water using N.I.Drozd's (1961) formula. From the values of the rates of sediment runoff it is possible with certain approximations to estimate the quantity of products of sheet erosion.

An analysis of the data of Table 1 makes it possible to delimit in the inter-river area between the Seym and Psel Rivers (Ponds Nos. 1-32) two districts which differ in their values of the rates of sediment runoff. The boundary between these districts follows approximately the

right bank of the Reut River (Fig. 1). Sheet erosion in the district west of this river ranges from 1.0 to 3.5 tons/ha/year; on forested catchments it decreases to 0.8-0.4 tons/ha/year. Somewhat further south, in the basin of the upper reaches of the Vorskla River, the rate of sheet erosion according to data on silting of three reservoirs is 0.7-1.3 tons/ha/year (Voskresenskiy, 1956). For the eastern district the rate of sheet erosion varies within relatively narrow limits: from 0.4 to 0.6 tons/ha/year.

Lidov and Nikolaevskaya (1956) in zoning the Mid-Russian Highlands according to present relief-forming processes classify its territory as a region of slight and moderate erosion within the zone of the southern variant of the forest steppe and delineate here two districts: 1) Timsko-Oskol'skiy (ridge land) a district of slight erosion - east of the Reut River and 2) the Vorsklo-Seymskiy (Central) District of moderate erosion - west of the Reut River. The zoning carried out by these authors on the basis of the development of erosion, deflation, landslide and karst processes is fully verified by data of direct measurements of the products of water erosion which accumulates in small artificial reservoirs.

The rates of sediment runoff computed from data of silting of four ponds in the basin of the upper reaches of the Oka River range from more than 8 to about 0.5 tons/ha/year (Table 1, Ponds Nos.33-36). According to the map of Lidov and Nikolaevskaya, Ponds Nos. 33, 34, and 35 lie in districts with slight erosion. Values of sheet erosion for the catchment areas of ponds Nos. 33 and 34 are 8.2 and 1.3 tons/ha/year respectively. For Pond No. 35 it is 0.5 tons/ha/year. Therefore, sheet erosion on the catchments of the first two ponds located on the left side of the Oka River is quite high (especially for Pond No. 33) for a district with slight erosion. In this case the

description of the district by Lidov and Nikolaevskaya does not agree with the morphometric indices of the erosion relief of this district given in the paper of E.A.Mironova for the Orel Province (1958). According to Mironova the greatest horizontal and vertical dissection on the left side of the Oka River occurs in the Orel Province. Steep slopes (greater than 6°) occur on more than 30% of the entire area of this district, i.e., on a much larger area than in other districts of this province. With this in mind and considering also the high erosion in this territory shown by our investigation, the area to the left of the Oka River should probably be classified as a region of moderate instead of slight erosion.

The very high value of the rate of sediment runoff for Pond No. 33 is due to the fact that its catchment area is being grazed and there is no vegetal cover on the lower slopes and the upper layer of the soil is loose.

The eastern part of the Orel Province (inter-river areas between the Krasivaya Mech' and Sosna Rivers in the Zush River Basin) are also highly dissected, albeit to a lesser degree than the left side of the Oka River (Mironova, 1958); according to Lidov and Nikolaevskaya this area belongs in regions with moderate erosion. The erosion on catchments of small ravines in the vicinity of the Novosil'skaya Gully Experiment Station and in the basin of the Rakovka River (left tributary of the Zush River) averages about 1 ton/ha/year, and on forested catchments it drops to 0.5 tons/ha/year (Voskresenskiy, 1956; data averaged for three years of observation, 1938-1940).

The south of the CCP (the basins of the Neruch' and Rybnitsa Rviers) is relatively weakly dissected and the percentage of the area in steep slopes is small (Mironova, 1958); according to Lidov and Nikolaevskaya (1956) this area is also included in the region of slight erosion

(Oksko-Sosnovskiy ridge region).

The part of the Voronezh Province within the mid-Russian and Kalachskaya Highlands is placed by Lidov and Nikolaevskaya in the region of severe and very severe erosion with individual areas of moderate erosion, and is sub-divided by them into a whole series of erosion regions (1956).

The results of a survey of small reservoirs show that sheet erosion in these regions is quite severe. Thus, in the headwaters of the Chigla River (left tributary of the Bityug River) in the Talovskiy District of the Voronezh Province (Table 1, Ponds Nos. 39-44) the rate of sediment runoff is 0.8-1.0 tons/ha/year. I.P. Sukarev's values based on a study of silting of a number of reservoirs in this district are higher - up to 2-4 tons/ha/year (1958). In his calculations Sukharev used a somewhat higher volume-weight of the silt deposit which he assumed to be 1 ton/m^3. In addition, he considered that 40% of the suspended sediment is wasted downstream, i.e., he assumed a trap efficiency of 60% for all the ponds which is also not quite correct. His computed value was therefore somewhat too high.

Sheet erosion is quite high also on the right side of the Don in the basin of the Veduga River - about 2 tons/ha/year; in the basin of the Chernaya Kalitva River it is about 1 ton/ha/year and more. These data were obtained by V.E. Vedenyapin from measurements of the thickness of bottom deposits in ponds (1961).

We have at our disposal also data on the silting of about 30 small reservoirs in the upper reaches of the Buzuluk River Basin (Sorokin and Yakovleva, 1960). This region adjoins the CCP on the southeast. Sheet erosion here ranges from 2 to 5 tons/ha/year.

Therefore, the rate of water erosion and thus the rate of silting of small artificial reservoirs in the CCP represents a quite serious problem.

C o m p u t a t i o n s   o f   d e n s i t y   o f   d e p o s i t s. The density or volume-weight is commonly expressed as the weight of the absolutely dry solid particles contained in a unit volume occupied by sediment in its natural moist state in the deposit of the reservoir. The value of the volume-weight is determined principally by the porosity of the deposits, which in turn depends on the particle size, degree of their uniformity, the content of organic matter, and on degree of compaction. Sediments deposits on the bottom of reservoirs are compacted in the course of time and by the pressure exerted by upper layers. In the process of compaction water is squeezed out of the deposit and the porosity is decreased. Sand is compacted very rapidly. In clay deposits the water is squeezed out slowly with the result that their compaction is also slow and gradual. The degree of compaction of clay material can be considerable.

Another factor which exerts a large influence on compaction of sediment deposited in reservoirs is the mode of their operation. In reservoirs which are being filled during the Spring high water and are subsequently emptied to a large extent, the deposit dries out and compacts more rapidly. Other conditions being equal the volume-weight of such deposits will be much higher than in reservoirs with small fluctuations in the water level, where the deposits are always covered with water.

Compaction is thus determined by the particle size, the weight of the above-lying layer of deposits, the extent and frequency of drying and the time during which the deposits accumulated.

The most dependable method of computing silting is from data of direct measurements of volume-weights of deposits. There are, however, very few such data at the present time.

Published data are available on volume-weights of suspended river sediment obtained by settling of samples in containers in the laboratory until the precipitate reaches a constant volume-weight (Polyakov, 1935). On the basis of this type of investigation B.V.Polyakov recommended that for Zavolzh'e conditions a volume-weight of 0.5 tons/m^3 (g/cm^3) should be used for the fine sediment material deposited in ponds. The author himself considers this value to be somewhat too low.

Volume-weights of deposits obtained by settling in cylinders can differ considerably from the actual density of deposits under natural conditions in the reservoirs. Volume-weights obtained by settling will depend on the experimental conditions: the diameter of the vessel, duration of settling, and the height of the column of the deposit (Lopatin, 1939).

A more substantial investigation of the density of bottom deposits was conducted in 1938-1940, by the Institute of Hydrology and Hydrotechnics, Acad. of Sci., Ukr. SSR. An expedition of this Institute surveyed about 50 reservoirs in the various regions of the Ukraine. On the basis of the collected data Myalkovskiy and Drozd (1947) established relationships between the volume-weight of deposits and their organic matter content (losses on heating) for three types of soils - sandy, clay, and heavy loam and silt. The relationship is of the following form:

$$\gamma = \frac{A}{l} + CT + B, \qquad (1)$$

where γ - volume-weight of deposits g/m^3; ℓ - losses on heating, %; T - period of silting of reservoirs, years; A, C, B - parameters, the values of which for various types of material are determined from a special table.

In the sandy category the authors include deposits with a small percentage of particles smaller than 0.01 mm; heavy loam and clay deposits are material containing a small number of elementary particles larger than 0.01 mm. The silt and loam types are deposits containing a small number of particles smaller than 0.001 mm.

In the second addition of his Hydrologic Computation, N.I.Drozd (1962) gives in addition to the above shown formula, also a table of values of volume-weights of deposits in small reservoirs of the Ukraine in relation to their type, the amount of organic inclusions, the value of the specific gravity of the mineral part of the deposit and the salt content. Salts (carbonates, sulphates, and chlorides) like organic substances reduce the volume-weight of deposits.

In 1956-1960 the Laboratory of Limnology with the participation of the author collected data on volume-weight of bottom deposits of 44 small reservoirs in the CCP. Average volume-weights of bottom deposits of these reservoirs computed as the arithmetic mean of the total number of samples (cores) taken in a given reservoir are presented in Table 1.

The analysis of the obtained data shows that the volume-weight is most closely related to the water content of the deposit (in percent by weight of the wet sample). This relationship is shown in Figure 2. The amount of moisture reflects the porosity of the material deposited in the reservoir and is a function of the mechanical analysis of the sediment, of the organic matter content and of the degree of compaction of the deposits. But this relationship cannot be used in practical computations because to do so it is necessary to previously compute the water content in deposits of the given mechanical analysis or to have this information beforehand.

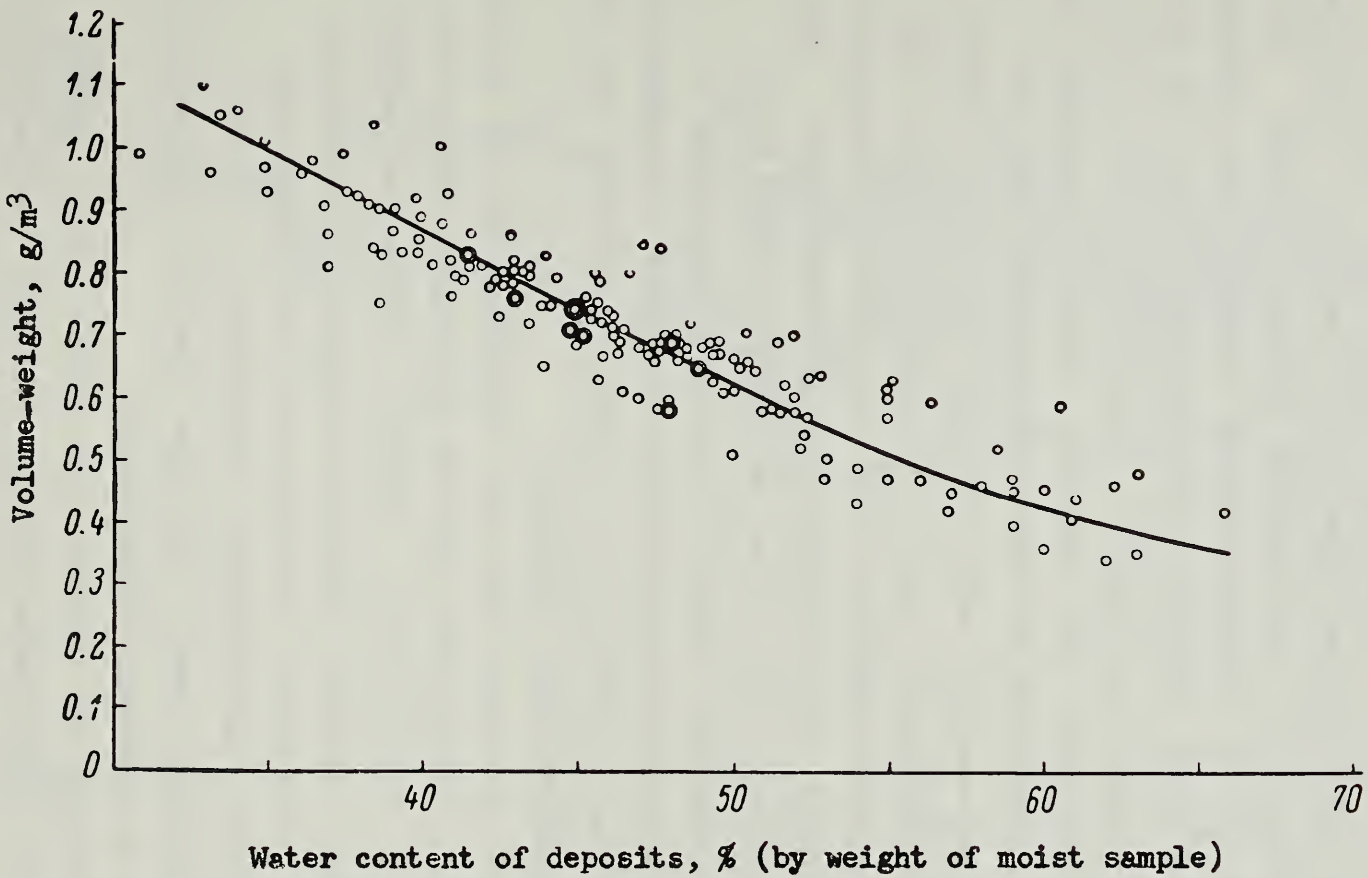

FIG. 2. RELATIONSHIP BETWEEN VOLUME-WEIGHT AND WATER CONTENT OF DEPOSITS

The relationship between sizes and volume-weights of deposits (Fig. 3) can be utilized in a tentative evaluation of the latter. The content of particles smaller than 0.01 mm is used as the size criterion. The lower envelope in Fig. 3 corresponds to densities of deposit layers not thicker than 10-15 cm,i.e., it corresponds approximately to the initial volume-weights. The upper envelope gives volume-weights of compacted sediment (with a thickness of deposits greater than 25-30 cm and an age of 10-30 years or more). Essentially this relationship reflects not only the increase in volume-weight with an increase in the size of the sediment but also the changes in volume-weight with changes in organic matter content of the deposits, since with an increase in the content of particles smaller than 0.01 mm the quantity of organic substances in the deposits also increases. The relationship between the sizes of deposits and their organic matter content (loss in heating) is shown in Figure 4. This relationship exists because in reservoirs the regions of sedimentation of organic residues and of fine mineral suspensions coincide.

Products of erosion from the surfaces of the catchments i.e., soil particles are the principal source of silting of small reservoirs. Studies of the mechanical analysis of soil samples show that organic substances of soils fall principally in the 0.005 to 0.001 and smaller than 0.001 mm fractions (Kachinskiy, 1958), i.e., mechanical analyses reveal the same laws of sedimentation which operate in natural reservoirs.

Average values of initial and final (i.e., after compaction over a prolonged period of time) volume-weights for four most frequently encountered types of deposits (Table 2) were derived from an analysis of all the samples of bottom deposits taken in the survey of small reservoirs in the CCP.

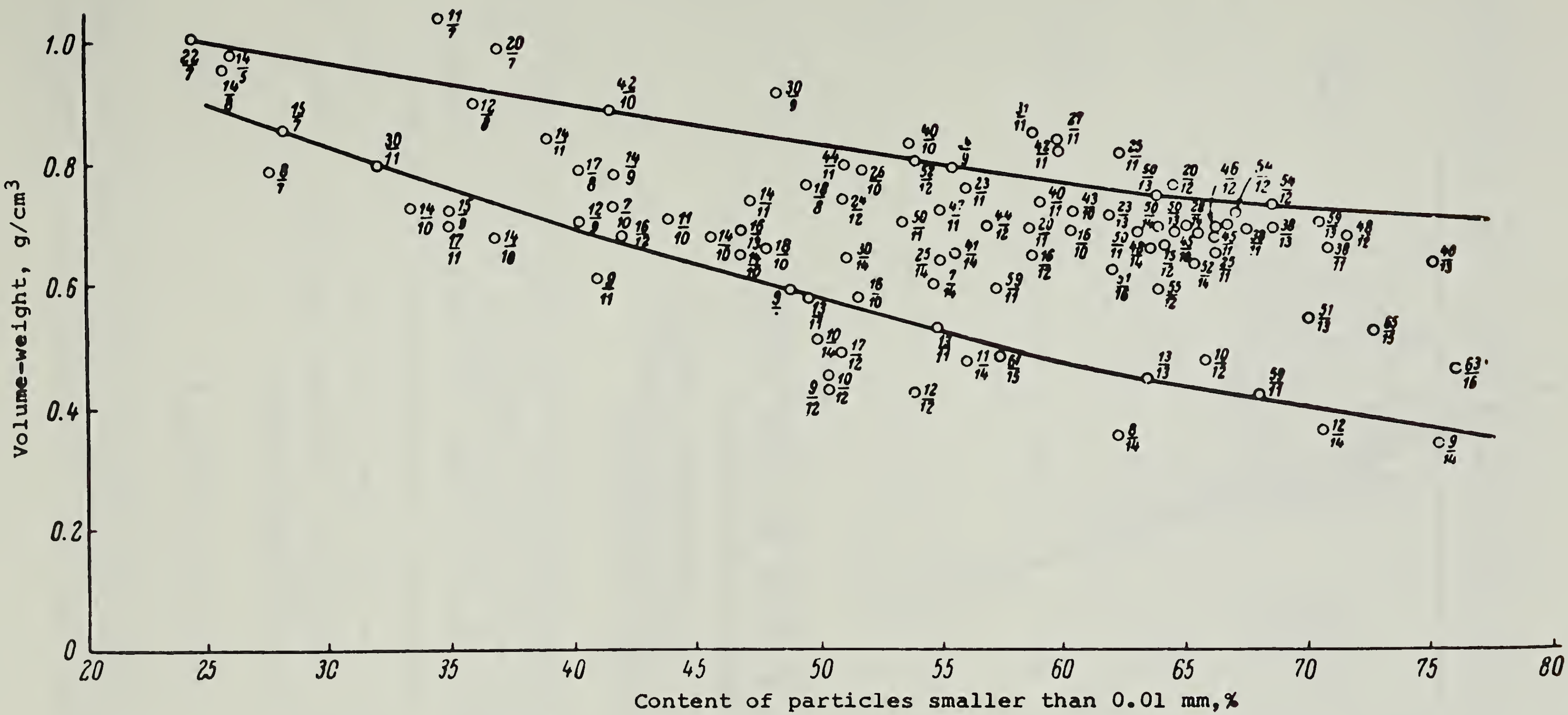

FIG. 3. RELATIONSHIP BETWEEN VOLUME-WEIGHT AND CONTENT OF PARTICLES SMALLER THAN 0.01 mm IN THE DEPOSIT.

In the numerator - height of column of deposit,cm
In the denominator - loss in heating,%

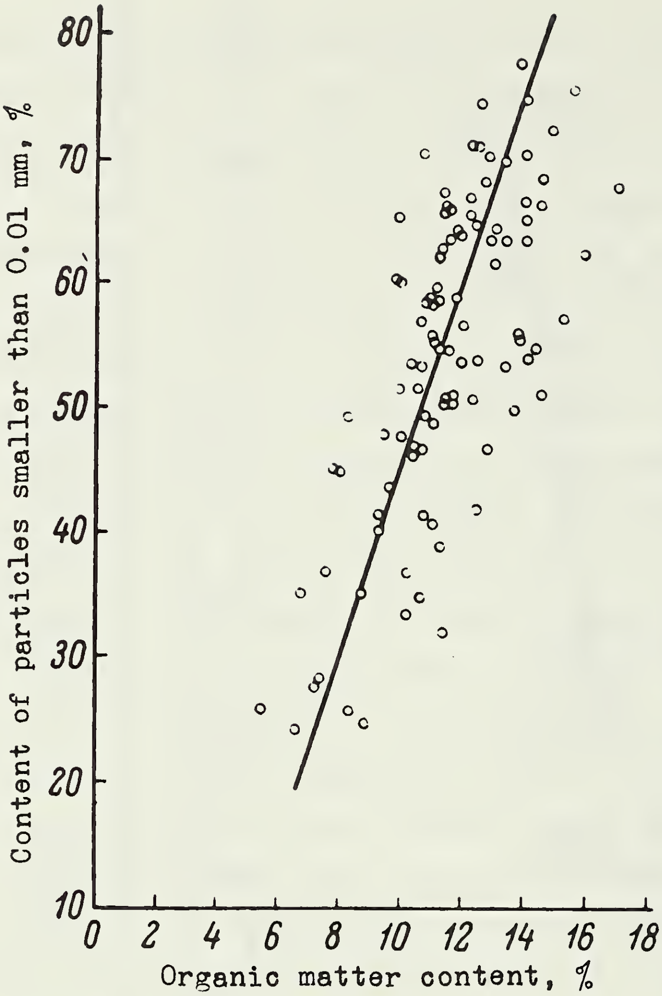

FIG. 4. RELATIONSHIP BETWEEN PARTICLE SIZE AND ORGANIC MATTER OF DEPOSITS

Extended investigations of the density of sediments deposited in reservoirs were conducted in the USA. On the basis of the obtained data Lane and Koelzer proposed a formula which relates the volume-weight of deposits to particle size, to the time period and to the mode of operation of the reservoir (Koelzer and Lara, 1958). The formula is of the following type:

$$W = W_0 + K \log_{10} T, \tag{2}$$

where W - density of the deposits after T years of compaction; W_o - density after one year of compaction; K - constant,

Table 2

INITIAL AND FINAL VALUES OF VOLUME-WEIGHT OF DEPOSITS IN RESERVOIRS OF THE CENTRAL CHERNOZEM PROVINCES

Type of deposit	Content of particles smaller than 0.01 mm, %	Loss in heating, %	Initial volume-weight g/m^3	Volume-weight after compaction g/m^3
Sandy silt	<30	6—8	0.90	1.00
Silt	30—50	8—10	0.70	0.90
Clayey silt . . .	50—75	11—14	0.45—0.50	0.75—0.80
Very clayey silt	>75	14—15	0.35	0.70

which depends on the type of deposits and mode of operation of the reservoirs and is related to compaction; T - the period of accumulation of deposits.

The Lane-Koelzer formula gives the density of a given layer of sediment after T years of compaction. The density of all the sediment deposited in T years must equal the average of the density of all layers from 1 to T years of compaction.

By integrating the Lane-Koelzer formula from 1 to T years Miller obtained the following formula for the average density of all sediment deposited in T years (Koelzer and Lara, 1958):

$$W_{cp.} = W_o + 0.434K \times \left[\frac{T}{T-1}(\log_e T) - 1\right]. \qquad (3)$$

where $W_{cp.}$ is the average density of deposits for T years of compaction; the other symbols being the same as in the preceding equation.

Table 3

VALUES OF W_o AND K AFTER TRASK (GARDE,1957)

Particle size, mm	Material (author's classification)	Parameter	Operation of reservoir: Always full	Operation of reservoir: Emptied moderately	Operation of reservoir: Emptied considerably
1.0—0.05	Sand	W_0 г/см^3 / K	1.41 / 0	1.41 / 0	1.41 / 0
0.05—0.005	Silt	W_0 г/см^3 / K	1.07 / 0.10	1.22 / 0.04	1.30 / 0.016
$<$ 0.005	Clay	W_0 г/см^3 / K	0.21 / 0.26	— / 0.17	— / 0.10

Values of W_o and K taken from the laboratory investigations of Trask are given for deposits of different sizes and for different modes of operation of the reservoir (Table 3).

If the deposits are a mixture and sand and of silt and clay then W_o and K can be computed considering the weight of each fraction of the sediment, i.e., according to the rule of mean-weighted value.

Using the survey data for the CCP reservoirs we verified and compared the volume-weights of bottom deposits calculated with the formula of Drozd and Myalkovskiy (1) and with Miller's formula (3).

The content of particles smaller than 0.01 mm in the deposits of small reservoirs of the CCP ranges from 25 to 75%. The range in the content of particles larger than 0.01 mm is about the same and applies principally to the 0.05-0.01 mm fraction. The content of particles smaller than 0.001 mm is 5-15% and in some cases even 20-25%. According to the

classification of Drozd and Myalkovskiy all the deposits with such a mechanical analysis belong in the group of silty deposits.

In cases where particles smaller than 0.001 mm constituted more than 20%, and the content of particles larger than 0.01 mm was 20-25% or more, the deposits were tentatively placed in the silty group.

For the group of silty deposits the Drozd and Myalkovskiy formula gives comparatively satisfactory results. Only in 25% of the cases did the errors in the calculation of volume-weight with this formula exceed 20% of the actual values.

Deviations greater than 20-50% were found for large ponds with ages up to 75 years and for a 6-year old reservoir. The thickness of the sediment deposit in the latter reservoir ranged from 5-10 to a maximum of 20-25 cm.

The errors in computing volume-weights with the Drozd-Myalkovskiy formula for sandy and clayey deposits were not determined because all the deposits of the small reservoirs in the CCP fell in the one category of silty deposits.

The shortcomings of the Drozd-Myalkovskiy formula are: a) some uncertainties with respect to the classification of deposits; b) large errors in the computation of volume-weight of deposits in old ponds and in recently constructed reservoirs; c) with a small amount of organic matter $(l < 1\%)$ the volume-weights for all types of deposits obtained with this formula are greater than their specific gravity, and with $l = 1\%$ are close to the specific gravity of these deposits.

The computation of volume-weights with Miller's formula (for deposits which are always under water) gives a considerably overestimated value in 90% of the cases. In 62% of the

cases the deviation from the actual values is greater than 20%.

Trask's high value of the initial volume-weight of silt particles (1.07 g/cm^3) can be noted in comparing Tables 2 and 3. This value exceeds the initial volume-weight of sandy oozes obtained by direct measurement in the reservoirs of the CCP. The results of the American investigator were, however, confirmed when the determinations of the initial volume-weights of different fractions of bottom deposits in reservoirs of the CCP were repeated at the Laboratory of Limnology (Table 4).

Along with the initial volume-weight the losses on heating and the humus content were also determined for each particle group. The differences in the volume-weights of the replicates of the largest particles are explained by the different content of organic matter.

In small reservoirs the sorting of incoming suspended sediment according to size is relatively insignificant. The material settling out at the bottom in the different parts of the reservoirs is usually a mixture of particles of different sizes ranging from sandy to clayey. Obviously, the porosity and therefore the density of a deposit consisting of uniform particles will be different from that of a deposit consisting of a mixture of particles of different sizes. This fact is probably one of the principal reasons explaining the difference between the initial volume-weights of deposits of different mechanical analyses, computed from initial volume-weights of different particle groups (even when, taking into account the percent content of each fraction) and the initial volume-weights of sediment in a reservoir under natural conditions.

More satisfactory results were obtained in computing volume-weights of deposits with Miller's formula using the initial volume-weights of the principal types of bottom deposits in small reservoirs of the CCP (Table 2) and the parameter K, computed by the Lane-Koelzer formula (2)

Table 4

RESULTS OF LABORATORY DETERMINATIONS (BY SETTLING) OF INITIAL VOLUME-WEIGHTS OF INDIVIDUAL FRACTIONS OF DEPOSITS FROM RESERVOIRS OF THE CENTRAL CHERNOZEM PROVINCES

Fraction, mm	Parameter	Replication								Average value
		1	2	3	4	5	6	7	8	
1.0—0.05	Volume-weight, g/cm^3.	1.33	1.60	—	—	—	—	—	—	1.46
	Losses on heating, %.	5.34	1.98	—	—	—	—	—	—	3.66
	Humus, %.	3.08	0.68	—	—	—	—	—	—	1.88
0.05—0.005	Volume-weight, g/cm^3.	0.82	0.99	1.11	1.12	—	—	—	—	1.01
	Losses on heating, %.	5.95	5.21	6.11	5.07	—	—	—	—	5.58
	Humus, %.	3.62	3.53	3.48	3.02	—	—	—	—	3.41
< 0.005	Volume-weight, g/cm^3.	0.25	0.20	0.24	0.29	0.27	0.26	0.27	0.31	0.26
	Losses on heating, %.		13.11		13.36	12.40	13.12	13.69	13.66	13.22
	Humus, %.		6.72		7.22	6.13	6.25	6.35	6.89	6.60

R e m a r k. Fractions of the deposit were separated by elutriation. The settling of the samples was done in a cylinder 2.5 cm in diameter.

taken from Table 2 (Table 5). The duration of the accumulation of the deposits was in this case taken to be equal to the average age of the deposits - 30 years (for clayey ooze W_o was taken to be equal 0.50 g/cm^3). The accuracy of the computation with this method was as follows: errors exceeding 20% of the actual volume-weights occur in 24% of the cases with the number of positive and negative deviations being about equal.

Table 5

VALUES OF PARAMETER K FOR DEPOSITS ALWAYS UNDER WATER ACCORDING TO DATA OF THE INVESTIGATIONS OF SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

Type of Deposit	K
Sandy silt	0.07
Silt	0.14
Clayey silt	0.20
Quite clayey silt	0.24

A comparatively good agreement between values computed by Miller's formula (the last variant) and actual values was obtained also for old ponds (age up to 75 years) for which the errors with the Drozd-Myalkovskiy formula were up to 50% and more. This speaks in favor of Miller's formula. The logarithmic change of the density of a deposit with time which shows a large compaction of deposited sediment in the first year and a rapid decrease in compaction in subsequent years reflects fairly well the actual process of compaction of bottom deposits in artificial reservoirs.

The merit of Miller's formula consists also in that with it the mode of operation of the reservoirs is taken into account. In reservoirs which are frequently or periodically emptied the deposits are subjected to drying. As a result such deposits are compacted considerably more rapidly than are those always under water.

Large deviation from actual values resulted with both the Miller and the Drozd-Myalkovskiy formulas for a reservoir which was only 6 years old, and also for one of the old ponds (65 years) the deposits of which have a somewhat higher organic matter content and a higher moisture content than do those of other ponds (on the side of higher volume-weights). Neither the Miller nor the Drozd-Myalkovskiy formulas take into account the rate of silt accumulation since for a given period the thicknesses of the deposited layers of sediment and therefore their densities can be different in different reservoirs.

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G. V. L O P A T I N

DEVELOPING A METHOD OF COMPUTING SILTING OF SMALL RESERVOIRS IN THE CENTRAL CHERNOZEM PROVINCES

The duration and effectiveness of the operation of small reservoirs depend on a series of circumstances. In the steppe and forest-steppe zones of our country the process of silting of reservoirs is of particularly great importance.

Records show that in a number of cases the silting of small reservoirs in the steppe and forest-steppe zones was quite rapid - silting reaching 4 to 6% (and sometimes more) per year of the initial capacity. With such rapid silting, reservoirs become of little use even after 10-15 years. Sometimes the considerable silting and the consequent increase in the water discharge result in the destruction of the main hydraulic structures which puts such reservoirs altogether out of commission.

In view of the abovesaid, the problems of computing the useful life of small reservoirs assumes considerable importance for the Central Chernozem Provinces (CCP). This paper is devoted to the discussion of this problem.

Causes of Silting of Small Reservoirs in the Central Chernozem Provinces

The principal causes (factors) of silting of reservoirs are: inflow into the reservoir of products of water erosion from the catchment (sediment runoff); inflow of products of bank destruction (abrasion); deposition in the reservoir of residues of plants and of animal life; precipitation of salts from solution, which subsequently become part of the deposit; deposition of substances brought in by industrial and sanitary sewage, and deposition of wind-carried material which falls into the reservoir.

The enumerated factors of silting can operate simultaneously and usually with different intensity and with varying effects. The prevalence of one factor over the others depends on local conditions.

Entry into the reservoirs of products of water erosion from the catchment is under conditions of the CCP, in most cases, the principal and decisive factor in the process of silting because natural conditions in these provinces are conducive to the development of water erosion. Records show that the annual rate of deposition of products of water erosion entering from the catchment into small reservoirs can reach quite large dimensions (up to 200-250 tons per km^2 of the catchment per year).

With a rate of silting of 250 m^3/km^2 a reservoir with a catchment of 10 km^2, a Spring runoff of 60 mm, and a capacity of 100,000 m^3 (with the usual ratio of surface areas to depth) will silt up by 23% in 10 years and in 20 years by 45%. The storing capacity of such a reservoir is taken to be about 90% of the incoming products of water erosion. However, the rate of silting of reservoirs can be considerably reduced by erosion control measures on the catchments and by protective measures in the gullies where the water approaches the reservoir. An example of this could be the two small reservoirs in the Kursk Province - Berezovyy and Zapovednik for which the rates of silting were reduced down to 20 and 31 m^3/km^2 by applying prescribed control measures (Lopatin and Yakovleva, 1958).

It should be pointed out that the rate of silting expresses only a part of the erosion from the catchment because a certain part of it (sometimes a rather considerable part) is detained enroute in the depression of the relief of the locality and in the backwater where the streams enter into the reservoir. In the latter case we have

the development of regressive accumulation. Moreover, the rate of silting does not reflect the products of water erosion (sediments) which are carried out of the reservoirs when part of the water is discharged downstream or is taken out for irrigation.

Under conditions of the CCP the process of silting of small reservoirs by products of water erosion from the catchment (sediment) is characterized by the following. The principal mass of sediment (up to 80-90% and more) enters during the Spring high water. A considerable part of sediment entering the reservoir, first settles at the upper reaches of the reservoir and then (during the remaining months of the warm period of the year) gradually moves on into the shallow parts under the influence of mixing by wave action and under the influence of reverse currents also toward the deeper parts of the reservoir.

This mode of translocation of sediment can be altered substantially by the bottom "density" currents formed by the difference between the specific gravity of the inflowing turbid water and that of the clear water of the reservoir. In these cases large quantities of sediment entering the reservoir will move as part of the bottom "density" current along the length of the reservoir forming a layer of deposits which is more or less uniform in thickness over the entire length of the reservoir (Lopatin, 1963).

The proportion of sediment translocated in the body of the water during the Spring high water is usually small; for instance, for the Borshchenskoe Reservoir it was about 13% in 1958.

With a slight overgrowing of the reservoir the translocation of sediment can proceed quite rapidly. When the vegetation growth is considerable an accumulation of sediment will occur in the areas where aquatic vegetation is developed.

Q u a n t i t y o f p r o d u c t s o f a b r a s i o n entering into a reservoir is considerably reduced with the reduction in its size since on small reservoirs wave action and abrasion cannot fully develop. However, abrasion processes depend not only on the size of the reservoirs but also on the geologic composition of the bank and on their steepness, on the protection of the slopes of the banks by vegetation, on the direction of prevailing winds, etc. It must also be remembered that the abrasion process gradually diminishes with the age of the reservoirs because the slopes of the shores become gentler and are stabilized by vegetation.

In individual cases landslides can occur on small reservoirs with steep slopes when the ground water level rises after the construction of the reservoir. The products of these landslides considerably increase the quantity of shore deposits in the total sediment in the reservoir.

S a l t s p r e c i p i t a t e d o u t o f s o l u t i o n which then become part of the deposit are usually not important under CCP conditions because the reservoirs of these provinces are weakly mineralized usually not more than 200 mg/lit (predominantly carbonate and calcium ions). However, the following phenomena can sometimes be observed. When the reservoir is emptied some salts (especially carbonates) precipitate in the drying part near the shore and as a rule do not dissolve later when the water level rises. These salts are thus eliminated from the salt balance and pass into the content of the shore deposits. In individual cases small reservoirs can be fed by mineralized ground water which increases their mineralization and correspondingly increases the precipitation of salts out of solution.

The deposition of residues of aquatic vegetation is often of greater importance in forming deposits in small reservoirs than the deposition of residues of animal life. The development of vegetation increases with the age of the reservoirs when shallow areas are formed. In a number of cases reservoirs may be overgrown by 70-80% with the amount of biomass reaching 300-400 g/m^2. This considerably accelerates the process of silting. Here it must be noted that with an increase in the organic matter content, the density (volume-weight) of the deposit is considerably reduced and the volume of the deposits correspondingly increases. Thus, for instance, when the organic matter content in the shallow deposits increase to 20-25% the volume-weight of the deposits decreases to 0.4 $tons/m^3$

In addition to higher forms of aquatic vegetation there is observed in many reservoirs the development of micro-aquatic vegetation as a result of which finely dispersed oozes are formed.

The deposition of substances brought into reservoirs by industrial and domestic sewage assumes increasingly greater importance in connection with the development of industry. These substances include slag in the water of mines; suspensions in the water of concentrating plants, of metallurgical and sugar factories; $A\ell_2O_3$ of aluminum production, suspensions of nitrogen fertilizer production; ash and peat soot from chimneys, etc. These types of substances reach considerable quantities, sometimes up to 50% of the surface runoff sediment. Industrial sediments are not inert suspensions, but enter actively into the chemical and biological processes in reservoirs and impair the quality of the water. As a result, ordinary life in such reservoirs dies out and only bacteria can exist.

D e p o s i t i o n o f p r o d u c t s t r a n s p o r t e d b y w i n d is, in most cases, slight under conditions of the CCP and is of no importance in the silting process. This phenomenon is notably manifested only in very dry years.

An examination of the principal causes of silting of small reservoirs under CCP conditions shows that in calculating the silting of these reservoirs principal attention must be directed to the entry of products of water erosion from the catchment. However, for individual specific reservoirs it is necessary to consider also some other factors of silting in conformity with local situations which are characteristic of a given reservoir.

Principal Methods of Computing Silting of Small Reservoirs

The problem of silting of reservoirs involves a number of tasks including two principal ones: the determinations of a) the rate of overall silting of the reservoir and b) the rate of silting of its individual parts which requires the determination of the path of translocation of sediment in the reservoir.

The second task which is of considerable interest for large and medium reservoirs is of no importance for small reservoirs because their efficiency will depend largely on the overall silting which changes the degree of regulation of the water flow that feeds the reservoir. For this reason this paper will deal only with methods for solving the first task.

As was already noted silting of the majority of small reservoirs in the CCP is due principally to the amount of sediment entering from the catchment. The rate of silting of such reservoirs is therefore determined by: the capacity and shape of the reservoir, by the quantity

and regime of the sediment-and water flows, by the size of sediment and their organic matter content, and also by the volume-weight (density) of the deposits.

The translocation of sediments in the reservoirs under the influence of water and wind currents can be determined for individual specific reservoirs by computations based on appropriate hydraulic laws, for instance, with the methods of G.I.Shamov (1954) and A.V.Karaushev (1960), however, these computations are quite difficult and laborious and can therefore not be recommended for mass planning of small reservoirs. In the simplification of methods of computing silting (especially desirable in the planning of small reservoirs and of ponds) it can be assumed that the reduction in the carrying capacity of the water in the backwater (upper) is determined by the degree of regulation of the water flow, i.e., in the simplest terms by the ratio of the volume of the reservoir to the volume of streamflow. A reduction in the carrying capacity of the flow leads in turn to the intensification of the process of sediment accumulation, i.e., to a more rapid silting of the reservoir.

Therefore, the rate of sediment accumulation or the trap efficiency of the reservoir expressed by the ratio of the annual amount of deposition in the reservoir to the annual quantity of solid substances entering into a given reservoir will depend in large measure on the index of regulation of water flow.

Thus, in determining the annual amount of deposition in a reservoir it is necessary to know the annual sediment flow and the trap efficiency of the reservoir.

Sediment flow can be determined by direct measurements on the catchment of the planned reservoir or by appropriate computation methods developed with due consideration of the natural conditions of the CCP. Some of these methods are presented in V.Ya.Frolov's paper (this volume).

The method of determining the index of trap efficiency of a planned reservoir as a function of the extent of regulation of the water flow is discussed in the next section of this paper.

Because sediment flow is usually expressed in weight units it is necessary to know the volume-weight (density) of the deposit of the given reservoir in order to arrive at the volume of the deposit.

Methods of determining the values of volume-weight of deposits in small reservoirs in the CCP are discussed in L.V.Yakovleva's paper (this volume).

Dependence of the Trap Efficiency of a Reservoir on the Degree of Regulation of Water Flow

The effect of degree of regulation of water flow by a reservoir on the accumulation of sediment was apparently first noted by B.V.Polyakov (1935). Later this question was discussed by several hydrologists in the USA (Brune and Allen, 1941; Brown, 1943; Gottschalk, 1948, and others). The extent of regulation of the water flow was first expressed by them as the ratio of the reservoir volume to the area of the catchment (W/F) and only later did they adopt the more correct expression in the form of (W/Q) i.e., the ratio of the volume of the reservoir to the volume of the annual water flow entering into a given reservoir. A summary paper on this question is the one by Brune (1952) in which he gives a graphical relationship between the trap efficiency (β) and the degree of regulation of the water flow by the reservoir (α) (Fig. 1). This relationship presented in the form of two envelopes and of an average line is based on data of silting of 40 reservoirs located in different parts of the USA predominantly in the southern and mountain regions. Information on the silting of these reservoirs is given in Table 1 in which Brune's numbering of the reservoirs

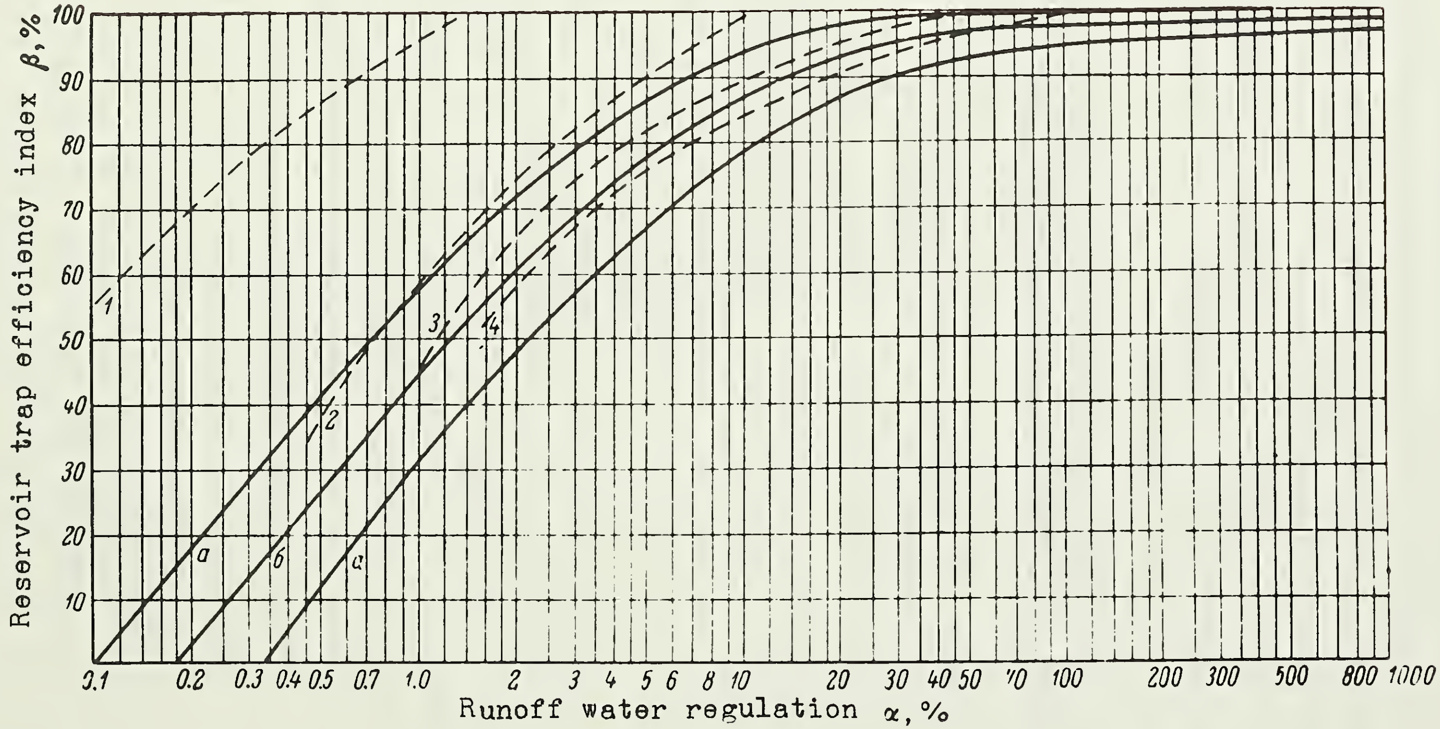

FIG. 1. RELATION OF TRAP EFFICIENCY OF RESERVOIRS $\beta = \frac{R_{av.}}{\Sigma R}$ TO RUNOFF-WATER REGULATION $\alpha = \frac{W_{av.}}{\Sigma Q}$.

a - envelopes; b - average regression line after Brune. 1,2,3,4 regression lines after N.I. Drozd (Table 4).

Table 1

DATA ON SILTING OF RESERVOIRS IN THE USA (AFTER BRUNE)

Reservoir	Location (State)	Catchment area, $F \cdot 10^3$ km^2	Age of reservoir	Reservoir capacity W_o, mill. lit.	$\alpha_{cp.}^{*} = \frac{W_o}{\Sigma V}$, %	$\beta_{cp.}^{*} = \frac{R}{\Sigma R}$, %	Avg. turbidity of runoff water, g/m^3
					*cp = av.		
	Normal impounding reservoirs						
1. Williams.	Indiana	12.2	9	6.85	0.16	0 (?)	430
2. Lake Halbert.	Texas	0.014	69	0.008	0.29	2.3	15800
3. Same.	"	0.004	69	0.003	0.41	5.8	15800
4. Hales Bar (1935—1936).	Tennessee	56.3	2	172	0.51	30.5	180
5. » » (1938).	"	56.3	1	171	0.51	29.7	180
6. » » (1937).	"	56.3	1	171	0.51	25.7	180
7. Keokuk.	Iowa	308	23	500	0.93	50.0	438
8. L. Taneycomo.	Montana	11.9	22	41.4	0.94	56.3	467
9. Wilson Lake.	Alabama	79.5	2	652	1.45	44.9	150
10. L. Marinuka.	Wisconsin	0.358	72	1.44	1.55	65.4	367
11. L. Decatur.	Illinois	2.34	24	21.0	3.38	78.0	451
12. Bullard's Bar.	California	1.24	19	37.0	3.78	83.4	227
13. L. Halbert.	Texas	0.003	69	0.021	3.78	69.3	15800
14. L. Rockwell.	Ohio	0.531	36	8.68	4.94	85.8	124
15. Corpus Christi (1942—1948)	Texas	43.4	6	51.0	5.41	73.7	1050
16. » » (1934—1942).	"	43.4	8	60.1	6.38	76.7	1050
17. Lexington.	No. Carolina	0.018	5	0.553	7.30	77.2	694
18. Lloyd Shoals.		3.66	24	129	8.07	81.4	524
19. L. Michie.	No. Carolina	0.433	9	15.3	9.98	86.3	404
20. L. Jssaqueena.	So. Carolina	0.036	11	2.15	12.7	94.2	1180
21. Guernsey.	Wyoming	41.9	20	222	15.1	92.2	2940
22. Arrowrock.	Idaho	5.61	33	338	17.1	93.0	474
23. T. and P.	Texas	0.016	8	0.427	19.1	87.0	3080
24. Hiwassee.	No. Carolina	2.50	1	537	27.3	98 1	224
24a. Imperial Dam (1938—1942)	Arizona	477	5	2640	21.1	90.2	28900
24b. » » (1943—1947).	"	477	5	862	6.86	72.3	28900
25. Lake of the Ozarks.	Montana	36.2	17	2490	29.2	96.7	862
26. Pardee.	California	1.11	14	257	31.3	95.0	103
27. Possum Kingdom.	Texas	36.4	8	862	78.7	98.0	7590
28. White Rock.	"	0.256	25	9.06	81.2	93.3	7710
29. Buchanan Lake.	"	54.3	7	1150	83.7	98.6	3000
30. Norris.	Tennessee	7.53	1	3270	94.6	99.1	322
31. Senecaville.	Ohio	0.313	5	108	94.7	94.3	989
32. H. Lage Pond.	Iowa	0.0001	11	0.015	122	100.0	18300
33. Denison.	Texas	99.0	6	7080	140	100.0	4960
34. L. Mead.	Nevada	434	13	38850	244	99.4	10000
35. San Carlos.	Arizona	33.3	18	1520	395	98.0	16700
36. Conchas.	New Mexico	19.0	10	936	382	97.3	13900
37. Fort Peck.	Montana	149	12	23800	465	100.0	1220
37a. Elephant Butte.	New Mexico	67.0	32	2960	205	98.6	13900
38. All-Americam Canal.	Arizona	477	10	13.8	0.11	91.7	5410
39. Hadley Creek, New.	Illinois	0.199	5	3.46	8.50	98.8	4270
40. John Martin.	Colorado	48.9	5	842	171	62.2	15600
41. Senecaville (1936—1939).	Ohio	0.313	3	108	95.3	48.4	989

R e m a r k. Ages of reservoirs are given to the nearest year. Reservoir capacity is the average for the age of the reservoir.

is used. The table contains the following data taken from Brune: catchment area, age of the reservoir prior to the sedimentation survey, average volume of the reservoir, and the indices of water regulation and of trap efficiency of the reservoir. All these values were converted by us into metric units and were somewhat rounded off.

In addition to the above information we computed, using Brune's basic data, the values of average turbidity of the surface runoff feeding each reservoir which are also given in Table 1.

In accordance with these data we divided all the indicated USA reservoirs into the following three groups according to the average turbidity of the surface runoff: from 100 to 500, from 500 to 10,000 and greater than 10,000 (in g/m^3) which are shown in the legend of Fig. 2. The distribution of the points on this graph made it possible to draw regression lines of β on α for two turbidity categories: from 100 to 500 (or less than 500) g/m^3 and greater than 500 g/m^3. Both of these regression lines naturally lie between the envelope curves drawn by Brune.

It should be pointed out that 3 poinds (Nos. 30, 40 and 41) in Fig. 2 fell away from the field of the other points of the considered relationship. This is apparently due to the peculiarities of these reservoirs and particularly to the conditions of their filling. In Reservoirs 40 and 41 which Brune placed in the "semi-dry" category the sediment on the days of the survey was apparently partially dried out and is therefore not fully represented by the sampling. Reservoir 38 which Brune placed in the "unsilted basins" category may possibly have some peculiar system of feeding due to the presence of an inflow canal. It is possible that the α and β values for this reservoir should be computed in some other way. In view of the above the three indicated reservoirs were not considered in subsequent calculations. The positions of the points and

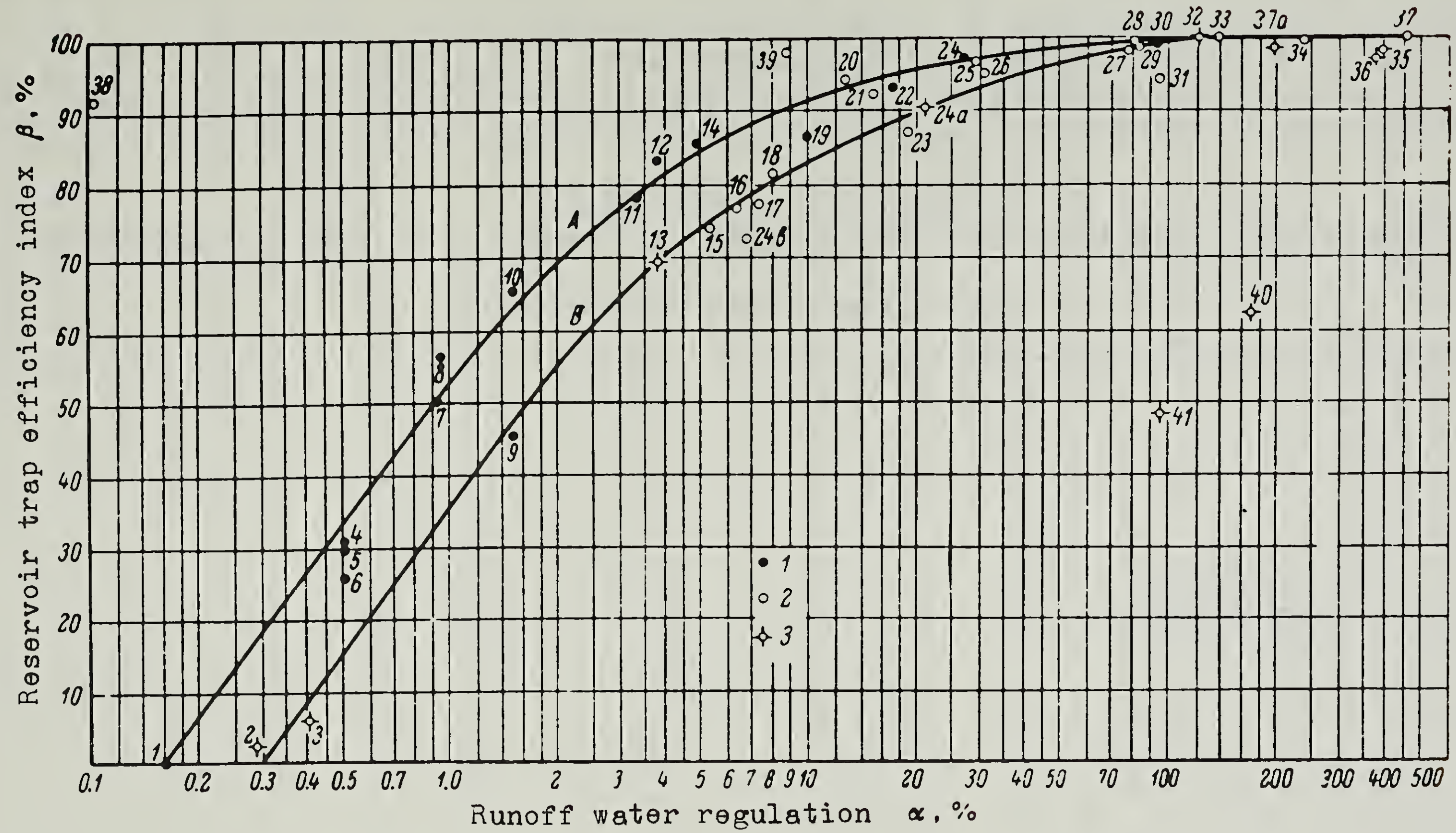

FIG. 2. RELATION OF TRAP EFFICIENCY OF RESERVOIRS β TO RUNOFF WATER REGULATION α AFTER G.V. LOPATIN.

Numbers at points on the graph correspond to those of the reservoirs in Table 1. Turbidity of surface runoff for the reservoirs is: 1 - <0.5; 2 - 0.5 to 10.0; 3 - >10.0 (in kg/m^3. A - regression line for turbidity <0.5 kg/m^3, B - for turbidity >0.5 kg/m^3.

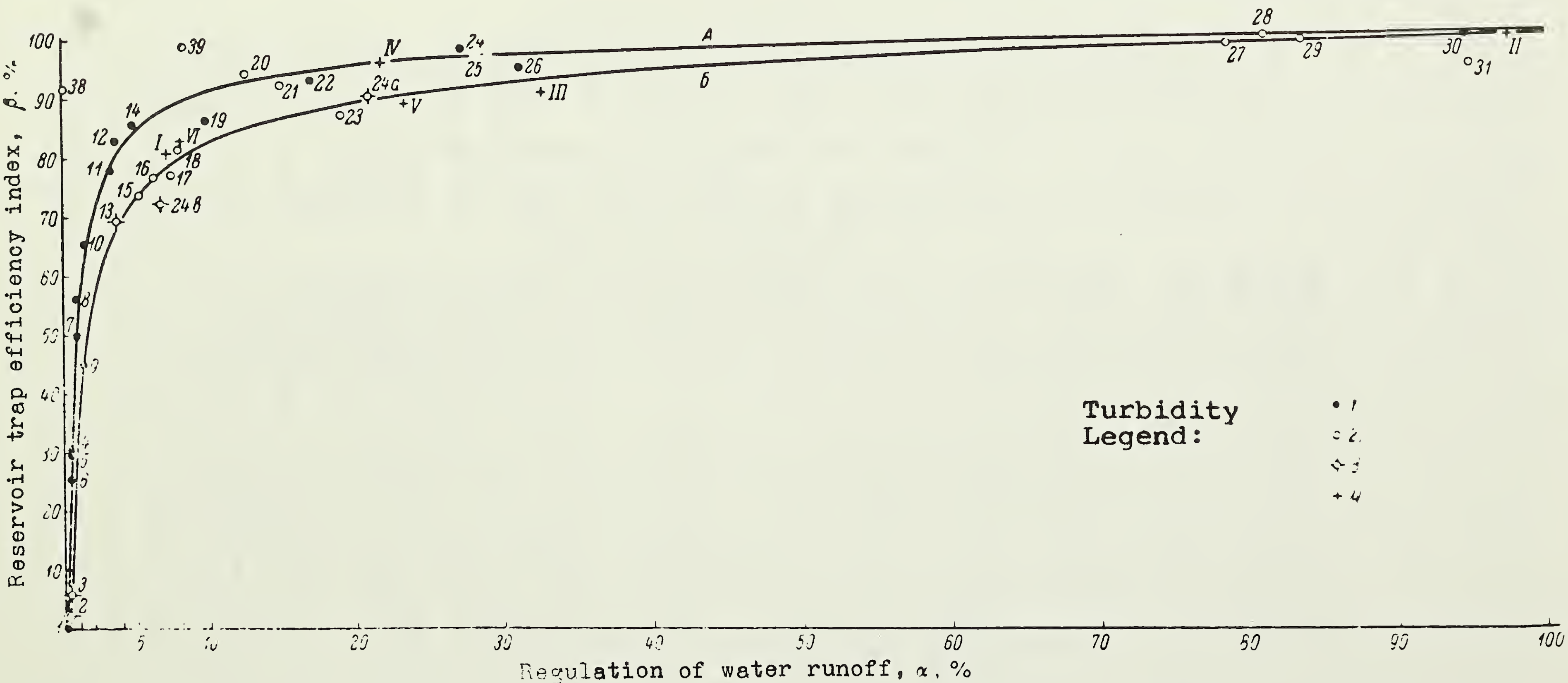

FIG. 3. RELATION OF TRAP EFFICIENCY OF RESERVOIRS (β) TO RUNOFF WATER REGULATION (α) AFTER G. V. LOPATIN

Number at points in the graph correspond to those of the reservoirs in Table 1 (Arabic numerals) and in Table 3 (Roman numerals). Turbidity of surface runoff for the reservoirs is: 1 - < 0.5; 2 - 0.5 to 10.0; 3 - > 10.0 (in kg/m^3); 4 - for turbidity for the points with Roman numerals see Table 3. A - regression line for turbidity $\rho < 0.5$ kg/m^3, B - for turbidity $\rho > 0.5$ kg/m^3.

of the regression lines in Fig. 2 show that the trap efficiency of reservoirs having the same index of regulation of water flow will be greater when the turbidity of the surface flow is low (less than 500 g/m^3), than when it is high (i.e., for $\rho > 500$ g/m^3). This can be explained by the fact that the increase in the turbidity of surface flow is, to a large extent, connected with the increase in the washing out of finer soil particles on the catchment, i.e., with inflow into the reservoir of finer sediments which could naturally (other things being equal) be carried out of the reservoir in relatively larger quantities. This explanation fully agrees with the accepted concept of the processes of erosion and of forming of sediment runoff on small catchments.

Our proposed regression lines of β on α presented in Figs. 2 and 3 have the shapes of irregular parabolas, which can be expressed analytically by the following equations:

for $\rho < 500$ g/m^3:

$$\beta = 92.4 \frac{(\alpha - 0.16)^{3.78}}{\alpha^{3.76}} \quad \text{when} \quad \alpha > 1.5\%), \qquad (1)$$

for $\rho > 500$ g/m^3:

$$\beta = 77.2 \frac{(\alpha - 0.30)^{2.38}}{\alpha^{2.32}} \quad \text{when} \quad \alpha > 1.0\%). \qquad (2)$$

The coordinates of these regression lines are shown in Table 2.

It should be noted that although the volume of the reservoir is often equal and even greater than the annual water flow (i.e., $\alpha \geqslant 100\%$), the trap efficiency of such reservoirs is actually not complete (i.e., $\beta < 100\%$), because in many cases in the operation of the reservoir part of the accumulated water is used in some way or another to meet requirements such as irrigation, domestic water supply, etc. With the removal from the reservoir

Table 2

VALUES OF β (in %) FOR A SERIES OF VALUES OF α (in %) BY EQUATIONS (1) and (2).

α	β for $\rho < 500\ g/m^3$ (1)	β for $\rho > 500\ g/m^3$ (2)	α	β for $\rho < 500\ g/m^3$ (1)	β for $\rho > 500\ g/m^3$ (2)
1	—	33	15	93.7	85.8
2	68.4	54.7	20	95.2	89.2
3	76.8	64.2	30	96.9	92.4
4	81.4	69.7	40	98.0	94.6
5	84.4	73.4	50	98.7	96.2
6	86.5	75.8	70	99.7	98.6
8	89.2	80.3	100	100	100
10	91.0	82.4			

of such water there is simultaneously removed also some quantity of sediment.

The verification of the graphically presented (Figs. 2 and 3) relationship $\beta = f(\alpha)$ on reservoirs in our country will be fully possible only after sufficient data are accumulated by investigations of silting of these reservoirs. In such investigations it is necessary to obtain for each reservoir the following information on the most important already mentioned factors of silting: mean annual water-and sediment flow, capacity of the reservoir (initial and for the year of the sedimentation survey of the reservoir), volume of deposits accumulated during the life of the reservoir, and volume-weight of the deposits. Some of the enumerated information (volume of deposits and their volume-weight and the volume of the reservoirs) can be obtained only in the field at the given reservoir. To obtain the other information (average annual water and sediment flow) requires many years of measurements at special gaging stations which for a number of reasons cannot always be accomplished. It is therefore often necessary to determine the average water-and sediment flow by various computation methods developed for a given region.

Of the relatively few data on silting of reservoirs in our country which meet the above requirements this paper utilized data for only 6 small reservoirs located in the forest-steppe and steppe zones (Table 3). Plotting the data for these reservoirs on the β vs. α graph (Fig. 3) shows that the six points lie within the spread of similar points for the US reservoirs (according to Table 1).

Information given in Table 3 requires an explanation. First of all, it is necessary to point out that the volumes of the deposits for each reservoir were obtained in the field (by measurement and sounding) directly in

Table 3

TRAP EFFICIENCY OF SOME SMALL RESERVOIRS IN THE USSR

Order No.	Reservoirs	Catchment area, km^2	Period of silting	Duration of silting	Avg. annual water runoff, $\Sigma Q \cdot 10^6$ m^3	Avg. annual sediment runoff $\Sigma R \cdot 10^3$ T	Avg. reservoir capacities for the considered period $W_{av.} \cdot 10^3$ T	Avg. annual amt. of deposits $R_{av.} \cdot 10^3$ T	Avg. indexes for the considered period		Source of information
									α, %	β, %	
I	Nelidovskoe (Kursk Prov.)	11.2	1951—1956	6	0.90	2.11	0.050	1.62	5.55	76.8	Lopatin, 1961.
II	Uspenskoe (Kursk Prov.)	32.5	1953/54—1959	6	2.53	6.59	2.45	6.59	96.8	100.0	Lopatin, 1963.
III	Shantal' (Saratov Prov.)	35.0	1923/24—1934	11	1.66	4.98	0.501	4.54	30.2	91.2	Polyakov, 1935. Kuznik, 1958.
IV	Borshchenskoe (Kursk Prov.)	47.0	1951—1956	6	3.76	8.24	0.797	7.91	21.2	96.0	Lopatin, 1961.
V	Yagodnoe (Saratov Prov.)	50.0	1924/25—1934	10	2.37	5.69	0.503	5.29	21.2	93.0	Polyakov, 1935. Kuznik, 1958.
VI	Syzranskoe (Ul'yanov Prov.)	4818	1929—1947	19	376	1050	23.0	813	6.12	77.4	Romanov, 1961.

these reservoirs in years corresponding to the end of the period of silting. The conversion of the volume of the deposits into weight units was made with volume-weights (density) of the deposits determined either directly for the given reservoirs (Nelidovskoe, Uspenskoe and Borshchenskoe) or by special experiments.

The average volume of the reservoir was computed as the half-sum of the initial and final capacity for the considered period of time. The final capacity was determined by field measurements while the initial was computed by adding to the final volume the volume of sediment deposited during the considered time period. For the Syzranskoe Reservoir the initial volume was also known from the design data.

The average annual water flow for the reservoirs in the Kursk Province was computed from K.P.Voskresenskiy's (1951, 1956) maps. For the reservoirs of the Saratov Province, this value was taken from B.V.Polyakov (1935) and for the Syzranskoe Reservoirs it was computed from the data for the "Rep'evka" gaging station on the Syzran' River (catchment area 4420 km^2).

The average annual sediment flow for the Uspenskoe and Borshchenskoe Reservoirs was computed by conversion of the mean long-term water runoff taking into account the bedload (20% of the flow of suspended sediment) and of products of abrasion. For the Nelidovskoe Reservoir the computations were made with the rate of sediment flow established for the Borshchenskoe Reservoir. The sediment flow for the reservoirs in the Saratov Province was computed by B.V. Polyakov's method. For the Syzranskoe Reservoir the sediment flow was determined from the data of the "Rep'evka" Station on the Syzran' River.

For all six reservoirs the average annual turbidity exceeds 0.5 kg/m^3 and is about 2-3 kg/m^3.

In discussing the relation of the trap efficiency of the reservoir to the degree of regulation of water flow it is necessary to mention also the analyses and proposals of F.O.Orth (1934), G.I.Shamov (1939) and of N.I.Drozd (1947, 1962). In this paper, however, only N.I.Drozd's proposals are considered because the approach of F.Orth and of G.I.Shamov was somewhat different from ours.

In the paper by M.V.Myalkovskiy and N.I.Drozd (1947) the discussed relationship is represented by the formula:

$$R_0 = \sum R\,[1 - \varphi\,(1 - \alpha)], \qquad \text{(a)}$$

where R_0 - the average annual quantity of sediment deposited in the reservoir over a period of years; $\sum R$ - average annual quantity of sediment entering the reservoir for the same period of time; α - index of regulation of water flow $(\alpha = \frac{W}{\Sigma Q})$; φ - a parameter, representing the trap efficiency of the reservoir as a function of sediment size. For sandy sediment $\varphi = 0.1$, for light loamy and for loess-like sediments $\varphi = 0.3$, for heavy loam $\varphi = 0.4$.

The Myalkovskiy - Drozd formula can be presented in the form:

$$\frac{R_0}{\Sigma R} = \beta = 1 - \varphi\,(1 - \alpha) \qquad \text{(b)}$$

and by substituting the assigned values φ and α the corresponding values of the trap efficiency of the reservoir β can be determined.

Thus, for light loam and loess-like sediments $(\varphi = 0.3)$, $\beta = 0.73$ when $\alpha = 0.1$ (10%); $\beta = 0.703$ when $\alpha = 0.01$ (1%); and $\beta = 0.70$ when $\alpha = 0.001$ (0.1%), i.e., the trap efficiency of the reservoir remains practically unchanged when the water regulation is reduced from 10 to 0.1%.

Yet, according to the relationships (Fig. 2) based on direct observations the index of trap efficiency (β)

changes quite considerably over this range in values of α (10-0.1%), namely: when α=10%, β=82.4%; when α=1.0%, β=33.0%; and when α=0.1%, β=0.0. The correctness of the Myalkovskiy-Drozd (1939) formula is therefore subject to question.

Later, in 1962, N.I.Drozd proposed new relationships between β and α applicable to four sediment sizes (coarse-sandy, fine-sandy, silty, and clayey). These relationships are presented in Figure 1 and in Table 4.

As seen from the comparison of Tables 2 and 4, and also of Figures 1 and 2 the orders of magnitude of Lopatin's and Drozd's values of the index β are comparatively close. Regrettably, N.I.Drozd does not give the basis for his proposed relationship between α and β; he only states that the trap efficiency of a reservoir established by him was confirmed by field observations for the following limits of α: 0.2-0.7% for coarse sand sediment, 0.6-3.0% for fine sandy, 1.5-60% for silt and 2.5-95% for clayey sediment.

It should be said that N.I.Drozd's attempt to establish a relationship between β and α as a function of the coarseness of the sediment deserves attention. In the future such a relationship must be thoroughly investigated and must be made precise. However, at the present time there are as yet not enough dependable data for a quantitative solution of this problem.

Nomograms of Silting of Small Reservoirs

In applying the established regressions of β on α (Figs. 2 and 3) and Equations 1 and 2 in the computation of silting of reservoirs it must be kept in mind that these relationships are based on values of the indexes $\beta_{av.}$ and $\alpha_{av.}$ computed for average conditions during the period of silting of each reservoir. Values of silting of reservoirs for

Table 4

RELATION OF TRAP EFFICIENCY OF A RESERVOIR (β, %) TO RUNOFF WATER REGULATION (α, %) AND TO SEDIMENT SIZE (AFTER N.I. DROZD)

Group	Sediment category	For indexes of runoff regulation α, %					
		0.1	0.5	1.0	5.0	10.0	50.0
1	Coarse sand . . .	50	99				
2	Fine sand . . .	10	35	(57) *	88	99	
3	Silty . . .	2	20	45	80	89	99
4	Clayey . . .	1	5	30	73	83	96

* Drozd's value is 70; we (the author) changed it.

individual years computed with the proposed relationships can therefore deviate quite considerably (to either side) from the actual rate of silting during these years because the values of sediment and water flow as well as other factors of the silting process can, in individual years, differ substantially from their average values for a more or less protracted period of time. The proposed relationships can therefore be used only in the computation of overall silting of reservoirs over some sufficiently long periods of time, not less than 5-10 years.

To facilitate the computations special graphs were prepared for the determination of the **annual loss of reservoir capacity (Figures 4 and 5) averaged over a certain period of time.**

The construction of these nomograms is based on the following simple analytical expressions:

$$\frac{R'_{cp.}}{W_{cp.}} = \frac{\beta_{cp.}\,\Sigma R}{\gamma_{cp.}\alpha_{cp.}\,\Sigma Q} = \frac{\beta_{cp.}\rho_{cp.}}{\alpha_{cp.}\gamma_{cp.}} = \frac{\rho_{cp.}^{*}}{\gamma_{cp.}\,\dfrac{\alpha_{cp.}}{\beta_{cp.}}}, \qquad (3)$$

*average

where R'_{cp} - annual volume of deposits averaged for the considered time interval (T); W_{cp} - average volume of the reservoirs for the same time interval. R'_{cp}/W_{cp} is therefore the average annual loss in reservoir capacity expressed in terms of the average volume of the reservoir for the time T. In our computations it is expressed in percent. With

$$R'_{cp.} = \frac{\beta_{cp.}\,\Sigma R}{\gamma_{cp.}},$$

where ΣR - average annual sediment runoff, tons; γ - volume-weight of the deposit, tons/m^3; $W_{cp.} = \alpha_{cp.}\Sigma Q$, where

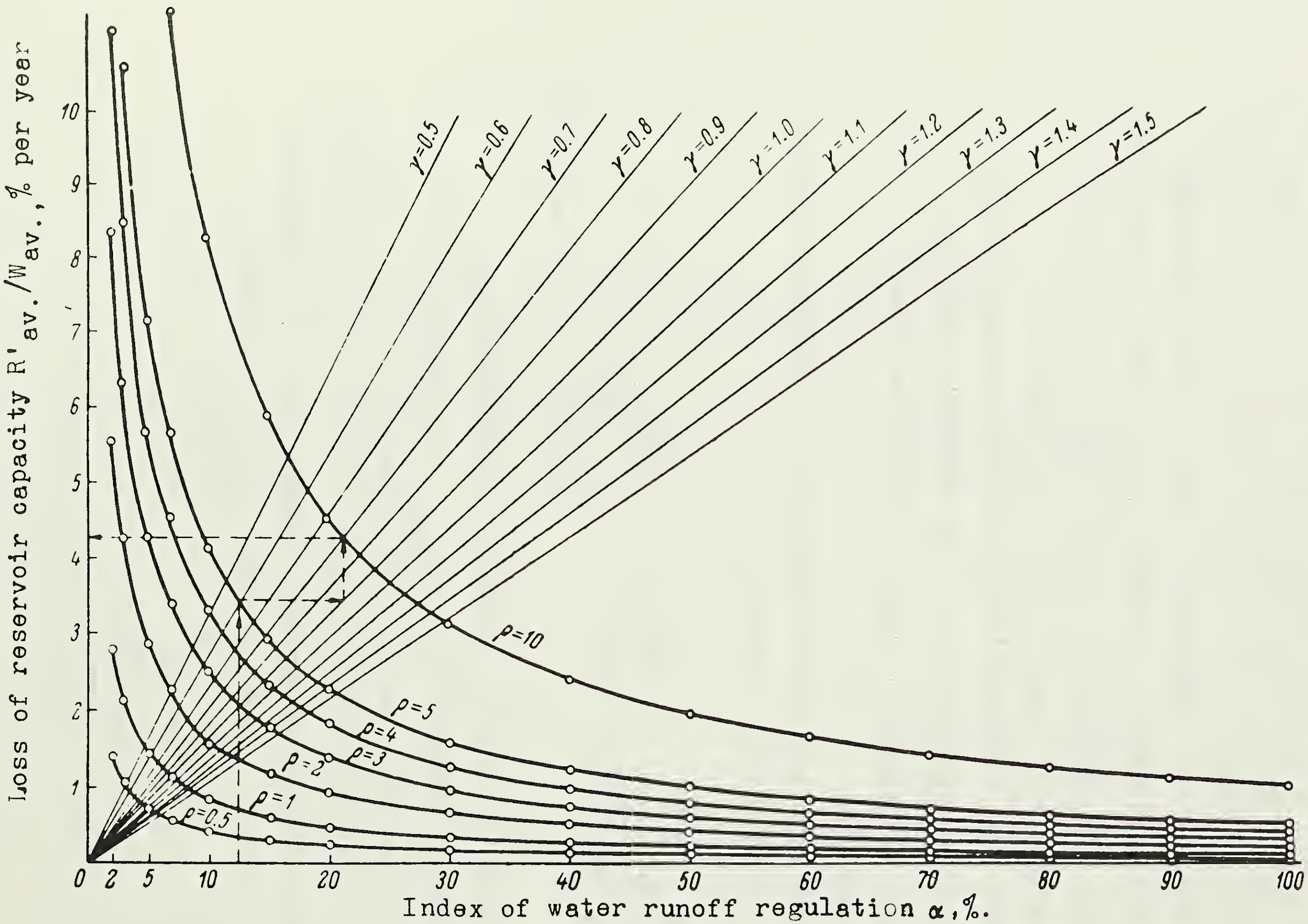

FIG. 4. NOMOGRAM FOR DETERMINING AVERAGE ANNUAL LOSS IN RESERVOIR CAPACITY $R'_{av.}/W_{av.}$, % AS A FUNCTION OF WATER RUNOFF REGULATION α, %; OF TURBIDITY OF SURFACE RUNOFF WATER ρ, kg/m^3; AND OF VOLUME-WEIGHT OF THE DEPOSIT γ, T/m^3

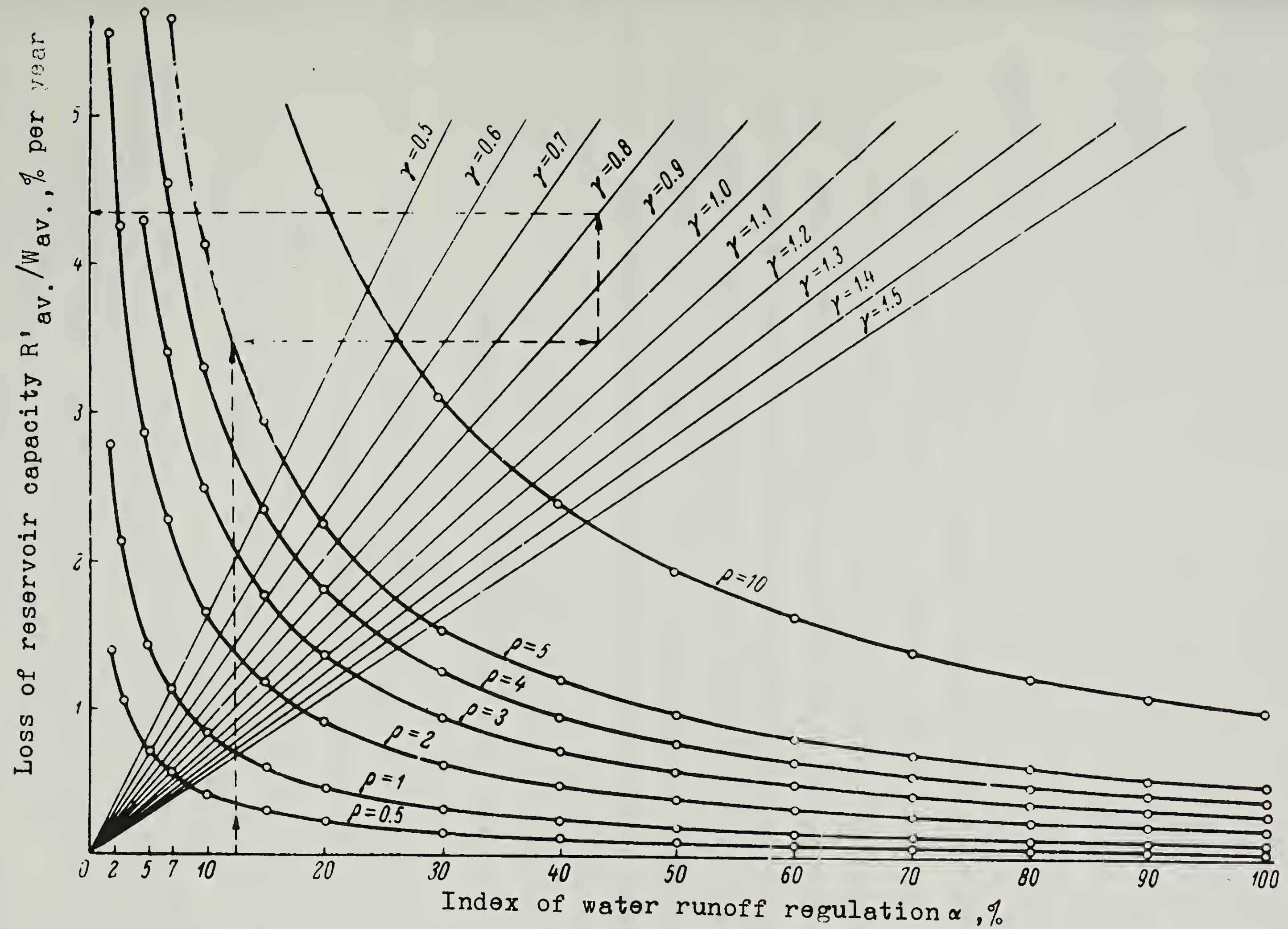

FIG. 5. NOMOGRAM FOR DETERMINING AVERAGE ANNUAL LOSS IN RESERVOIR CAPACITY $R'_{av.}/W_{av.}$, % AS A FUNCTION OF WATER RUNOFF REGULATION α,%; OF TURBIDITY OF SURFACE RUNOFF WATER ρ, kg/m^3; AND OF VOLUME-WEIGHT OF THE DEPOSIT γ, T/m^3.

ΣQ - the average annual water flow, and α_{cp} - the index of regulation of water flow for the periods T, then, substituting these expressions for R_{cp} and W_{cp} we obtain Formula (3).

Thus, knowing the average annual turbidity of the water flow ($\rho_{cp.}$ kg/m^3), the average volume-weight of the deposits ($\gamma_{cp.}$, tons/m^3), and the ratio α_{cp}/β_{cp} it is possible with Equation (3) to compute the value of the average annual loss of reservoir capacity for some period of time (T) in terms of the average volume of the reservoir for the same period of time.

The ratio α_{cp}/β_{cp} can be obtained from the established relationship between β and α (Figs. 2 and 3).

Practically the computation of silting with the established relationships reduces to the determination of the duration of silting of the reservoir up to an assigned limit (for instance up to 50% of the initial capacity. Then knowing the initial capacity (W_o) and the final (assigned) capacity (W_k=0.5 W_o), it is possible to determine the average capacity for the considered period of time by

$$W_{cp.} = \frac{W_0 + W_{\kappa}^{*}}{2}. \qquad \text{*Final}$$

Next are computed $\alpha_{cp.} = \dfrac{W_{cp.}}{\Sigma Q}$ and β_{cp} from the regression line of β on α (Figs. 2 and 3).

Substituting in Equation (3) the known values $\rho_{cp.}$, $\gamma_{cp.}$; $\alpha_{cp.}$ and β_{cp} we obtain the values R'_{cp}/W_{cp} and then the values R'_{cp}.

The sought duration (T) of silting up of the reservoirs to 50% of its initial capacity is obtained by dividing 0.5 W_o by R'_{cp}. The computation of silting with the proposed nomograms (Figs. 4 and 5) is done in the following manner.

Example of Computation

S t a t e m e n t of the problem. It is necessary to determine the time of silting of reservoir N to 50% of its initial volume (capacity). The initial capacity is W_o=1330 m^3, the average annual water flow $\sum Q$ =8000 m^3, the average annual turbidity $\rho_{cp.}$ =5 kg/m^3, the average volume-weight of the deposits $\gamma_{cp.}$=0.8 tons/m^3.

S o l u t i o n. The index of regulation of the water flow on the average for the considered period of time (T) will be:

$$\alpha_{cp.} = \frac{W_0 + 0.5W_0}{2\sum Q} = \frac{998}{8000} = 0.125 \text{ или } 12.5\%.$$

On the graph (Figs. 4 and 5) vertical lines are drawn from the found value of α_{cp}=12.5% to the intersection with the curve which corresponds to an annual turbidity $\rho_{cp.}$ =5 kg/m^3; from this point of intersection (a) a horizontal line is drawn to the intersection with the straight line which corresponds to the volume-weight of the deposit $\gamma_{cp.}$=1.0 (point b), then - a vertical line is again drawn to the intersection with the straight line corresponding to the volume-weight of the deposits of the given reservoir $\gamma_{cp.}$ (point c); after which following the same horizontal line the value of R'_{av}/W_{av}, % - (point d) is read on the vertical axis of the graph. In this case R'_{av}/W_{av}=4.25%.

All these determinations are shown in Figs. 4 and 5 by dotted lines. The value of the mean annual volume of deposits in the reservoir will then be R'_{av} = 0.0425; W_{av} = 0.0425X998 = 42.4 m^3.

Therefore, the time required for the reservoirs to silt up to 50% of its capacity will be

$$T = \frac{W_{silt.}}{R'_{cp}} = \frac{0.5W_o}{R'_{cp}} = \frac{665}{42.4} = 16 \text{ years}$$

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M. Ya. P R Y T K O V A

COMPUTATIONS OF TIME OF SILTING OF PONDS

In connection with the great practical importance of reservoirs in the arid regions of the country groups of scientists conducted during the recent decade large expeditions and surveys of small reservoirs. Especially valuable data were obtained by the GGI (State Hydrologic Institute) Expedition which surveyed the ponds of Kazakhstan (Voskresenskiy, 1958; Lisitsyna, 1960) and by the Laboratory of Limnology, Academy of Sciences, USSR on the ponds of the Kursk, Orel, Voronezh, and Volgograd Provinces (Lopatin, 1958, 1961, 1962; Sorokin, 1961; Sorokin and Yakovleva, 1961; Yakovleva, 1958, 1961, 1963). The results of the surveys of ponds in the Ukrainian SSR carried out by the Institute of Hydrology and Hydrotechnics, Academy of Sciences, Ukr. SSR in 1937-1939 (Myalkovskiy and Drozd, 1947; Drozd, 1958, 1961, 1962), of the ponds of the Trans-Volga surveyed in 1950 by the Lengiprovodkhoz (Voskresenskiy, 1956), of the ponds of Stravropol' surveyed by Sevkavvoproizom in 1938 (Mikhalchenkov, 1949) and of others are still of considerable value. Thus a large amount of data was accumulated on the silting of reservoirs under different physical-geographical conditions. These data make it possible to improve the previous methods of computing the time of silting of ponds.

Of the previously known formulas used in the calculation of the annual volume of deposits in ponds we shall consider the formula of B.V.Polyakov and that of M.B.Myalkovskiy and N.I.Drozd. Polyakov's formula (1935) was intended for the computation of the annual volume of deposits in closed (non-flowing) ponds and has the form:

$$\frac{R_0}{\rho Q} = \frac{1}{\gamma_1} + \frac{P}{\gamma_2}, \qquad (1)$$

where R_o is the mean annual volume of deposits in the pond, m^3; ρ - mean annual turbidity, g/m^3; Q - mean annual water flow, m^3; γ_1 - volume-weight of suspended sediment in the deposit, $tons/m^3$; γ_2 - volume-weight of bottom deposit, $tons/m^3$; P - bottom deposit expressed as a part of the suspended load.

Formula (1) does not take into account the effect of outflow on the silting of reservoirs and is therefore of limited application.

The Myalkovskiy-Drozd (1947) formula has the form of:

$$\frac{R_0}{R} = 1 - \varphi(1 - \alpha), \qquad (2)$$

where R_o/R is the trap efficiency of ponds which is the ratio of the annual volume of deposits (R_o, m^3) in the pond to the annual sediment runoff (R, m^3); φ - the coefficient of sediment size the following values of which are recommended. φ =0.1 for sandy sediment, φ =0.3 for light loam and loess-like sediment; and φ =0.4 for heavy loam; α - coefficient of pond capacity which is the ratio of the volume of the pond (W, m^3) to the volume of the annual water flow (Q, m^3).

In the Myalkovskiy-Drozd formula the trap efficiency of reservoirs is a function of the degree of regulation of water flow by the pond and of the size of the incoming sediment. The effect of the degree of regulation of flow on the storage capacity of reservoirs was pointed out earlier by B.V.Polyakov (1935). Later this thesis was confirmed by the work of the Institute of Hydrology and Hydrotechnics of the Academy of Sciences, Ukr SSR (Myalkovskiy and Drozd, 1947; Drozd, 1958, 1961, 1962) and by the work of a number of authors (Lisitsyna, 1960; Lopatin, 1963; Prytkova, 1960; Sorokin and Yakovleva, 1961), and also in the works of foreign investigators (Brune, 1953).

Brune's paper pointed out in particular that the ratio of the volume of the reservoirs to the inflow W/Q is more closely related to the trap efficiency of the reservoirs R_o/R than is the ratio of the volume of the reservoir to the catchment area W/F, which was widely used in the past.

The structure of Formula (2) requires some improvement. When the capacity coefficient of the pond α is close to 0 which corresponds to the old age of the pond the trap efficiency of the pond will by Formula (2) be equal $R_o=1-\varphi$ and will range from 0.9 to 0.6 depending on the sediment size coefficient φ used in the computation. Theoretically the trap efficiency must approach zero when α is close to zero.

In 1953 in analyzing the published data on trap efficiency of reservoirs in various countries Brune proposed the graphical relationship $R_o/R=f(W/Q)$, which was subsequently widely used by a number of authors both in deriving the sediment runoff from the volume of the deposits in ponds (Lisitsyna, 1960; Prytkova, 1960; Sorokin and Yakovleva, 1961), as well as in computing the time of silting of reservoirs (Lopatin, 1962).

However, the question of the trap efficiency of ponds remained as previously insufficiently worked out and required the setting up of special investigations on existing reservoirs.

For this reason the author (Prytkova, 1960) proposed in 1955 a graphical method of expressing the relative annual silting of reservoirs as a function of the principal factors which determine it; the capacity coefficient of ponds $\alpha_{av}=W/Q$ and the annual turbidity of the stream ρ. By the relative annual silting of ponds is meant the ratio (in %) of the mean annual volume of silting $R_{o,av.}$ (in m^3) to the initial volume of the ponds W_o (m^3), i.e., $C_{cp}=R_{o,cp}:W_{o}$, %.

The relative annual volume of ponds C_{av} can to a certain extent characterize their trap efficiency $\beta_{cp} = R_{o,cp} : R$ %, which as was noted above is considerably more difficult to evaluate without setting up special observations on the reservoir. This follows from the simple relationship

Average

$$C_{cp.} = \frac{R_{0,\,cp.}}{W_0} = \frac{\beta_{cp.} \cdot R}{\alpha_0 \cdot Q \cdot \gamma} = \rho \frac{\beta_{cp.} \cdot}{\alpha_0 \cdot \gamma}, \qquad (3)$$

where C_{cp} is the average relative annual volume of silting of reservoirs, %; $R_{o,cp}$ - average annual volume of deposits in the pond, m^3; W_o - initial volume of the pond, m^3; R - average annual sediment runoff, kg; Q - average annual water flow, m^3; β_{cp} - average trap efficiency of the pond, %; α_o - initial capacity coefficient of the pond; ρ - average annual turbidity, kg/m^3; γ - volume-weight of deposits, kg/m^3.

It is seen from Expression (3) that the trap efficiency of reservoirs is directly related to their relative annual silting and furthermore, depends on the hydraulic regime of the pond (the extent of its outflow, expressed by the capacity coefficient of the pond), turbidity, and on the volume-weight of the deposits (size of deposits according to M.V.Myalkovskiy and N.I.Drozd). The computation of silting of ponds is complicated by the large number of factors which determine the trap efficiency of ponds and by the almost complete lack of field measurements of this value on small reservoirs. In developing methods of computation of silting of ponds it becomes necessary to find empirically other relationships in which the results of surveys are utilized when it is not possible to obtain information on their trap efficiency. The author's above-mentioned method is an example.

This paper verifies the possibility of utilizing the relationship $C_{cp.}=f\ (\alpha_{cp.},\ \rho)$ in computing the time of silting of ponds under different physical-geographical conditions including those of the Central Chernozem Provinces (CCP). For this purpose we plotted on the logarithmic graph of $C_{cp.}=f\ (\alpha_{cp.},\ \rho)$, (Fig. 1) the results of a sedimentation survey of ponds located in the Kursk (Sorokin and Yakovleva, 1958), Orel (Yakovleva, 1964), in the Voronezh (Yakovleva, 1964) and Volgograd (Sorokin, 1958) Provinces; in Kazakhstan (Lisitsyna, 1960); and in the Ukrainian SSR (Myalkovskiy and Drozd, 1947). Altogether data for 166 ponds are plotted on the graph. Of these 46 are located in the Ukraine, 32 in the Kursk Province, 4 in the Orel Province, 8 in the Voronezh Province, 33 in the Volgograd Province, 12 in the Tselinograd Province, 14 in the Kustanayskaya Province, 9 in the Kokchetavskaya Province, and 8 ponds in the Pavlodarskaya Province of the Kazakh SSR.

An examination of the $C_{cp.}=f\ (\alpha_{cp.},\ \rho)$ graph shows that the points for the reservoirs located in the enumerated regions do, with rare exceptions, fall well within the gradations of mean annual turbidity delineated in Fig. 1. This is due to the small difference in the volume-weight of the deposits in the ponds (Lisitsyna, 1960; Lopatin and Yakovleva, 1958; Prytkova, 1960; Sorokin and Yakovleva, 1961; Yakovleva, 1958, 1961, 1963). The departures of individual points into the lower turbidity zones are apparently due to the low values of the volume of deposits obtained in the field. The departures into the zones of higher turbidity are due to the low values of annual water flow which, as a rule, are determined from the runoff map. These deviations cannot, however, change the general regularity established by the large number of points.

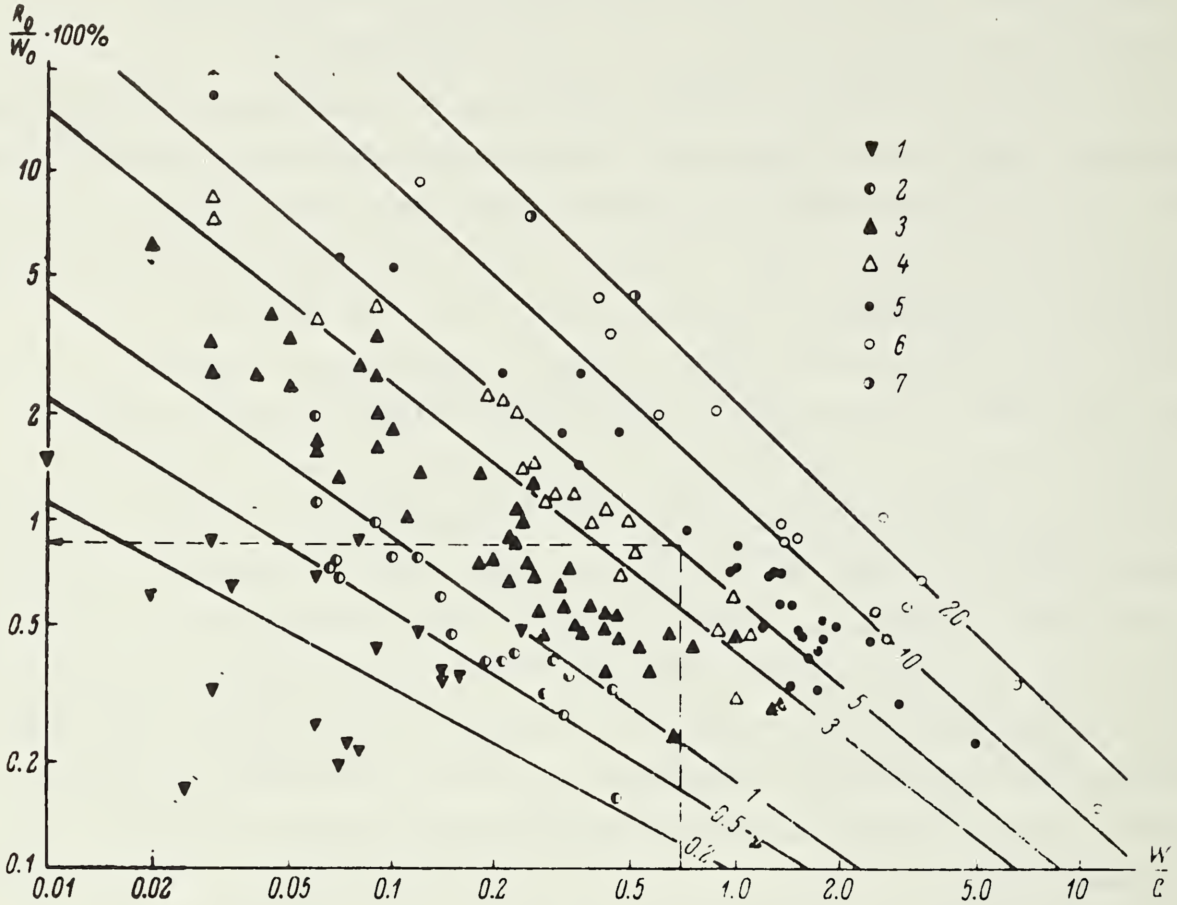

FIG. 1. RELATION OF THE RELATIVE ANNUAL SILTING OF RESERVOIRS R_o/W_o % TO THEIR CAPACITY COEFFICIENT W/Q AND TO THE AVERAGE ANNUAL TURBIDITY ρ, kg/m³

1 — ρ < 0.5 кг/м³; 2 — ρ = 0.5—1 кг/м³; 3 — ρ = 1—3 кг/м³; 4 — ρ = 3—5 кг/м³; 5 — ρ = 5—10 кг/м³; 6 — ρ = 10—20 кг/м³; 7 — ρ > 20 кг/м³.

The analytical relationship $C_{cp} = f(\alpha_{cp.}, \rho)$ can be represented in the form:

$$C_{cp.} = \frac{A}{\alpha_{cp.}^{n}}. \quad (4)$$

*Average

The values of the parameters A and n in Equation (4) are given in the table.

VALUES OF PARAMETERS A AND n IN FORMULA (4)

Mean Annual Turbidity kg/m^3	A	n
20	2.00	1.06
10	1.06	0.98
5	0.58	0.87
3	0.37	0.83
1	0.21	0.65
0.5	0.14	0.56
0.2	0.11	0.47

As seen in the table the parameters A and n vary with the mean annual turbidity. Graphs $n=f(\rho)$ and $A=f(\rho)$, which can be used in determining these values when computing the time of silting of reservoirs are shown in Figure 2.

Analytically the relationship $n=f(\rho)$ can be expressed in the form:

$$n = 0.69\rho^{0.12}, \quad (5)$$

and the relationship $A=f(\rho)$ by

$$A = 0.11(\rho + 0.8), \quad (6)$$

where ρ is the mean annual turbidity, kg/m^3.

Expression (6) for the determination of parameter A holds for $\rho > 0.4$ kg/m^3. When $\rho < 0.4$ kg/m^3 $A = 0.3\rho$.

With Equations (5) and (6) the formula for the determination of the relative annual volume of silting will be written thus:

$$C_{cp.} = \frac{0.11(\rho + 0.8)}{\alpha_{cp.} \cdot 0.69\rho^{0.12}}. \quad (7)$$

Formula (7) holds when $\rho > 0.4$ kg/m^3. For $\rho < 0.4$ kg/m^3 the relative annual volume of silting can be computed with the formula

$$C_{cp.} = \frac{0.3\rho}{\alpha_{cp.} \cdot 0.69\rho^{0.12}}. \quad (8)$$

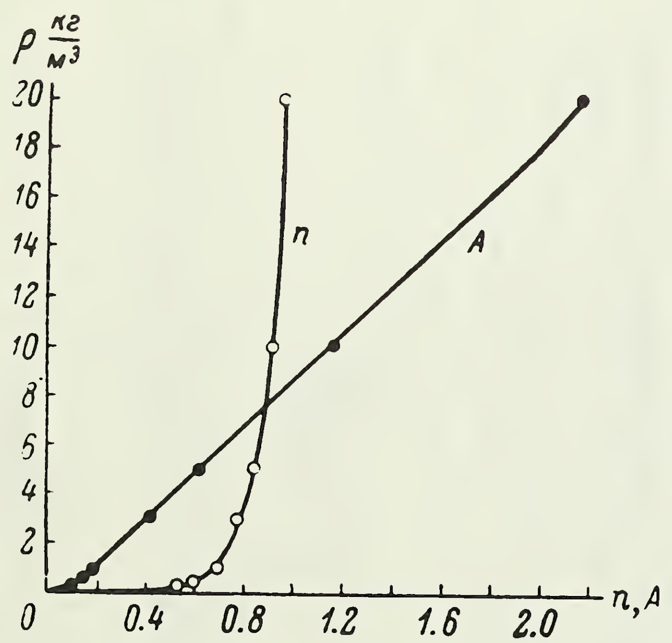

FIG. 2. RELATION OF n AND A FORMULA (4) TO THE MEAN ANNUAL TURBIDITY OF THE STREAM ρ, kg/m^3.

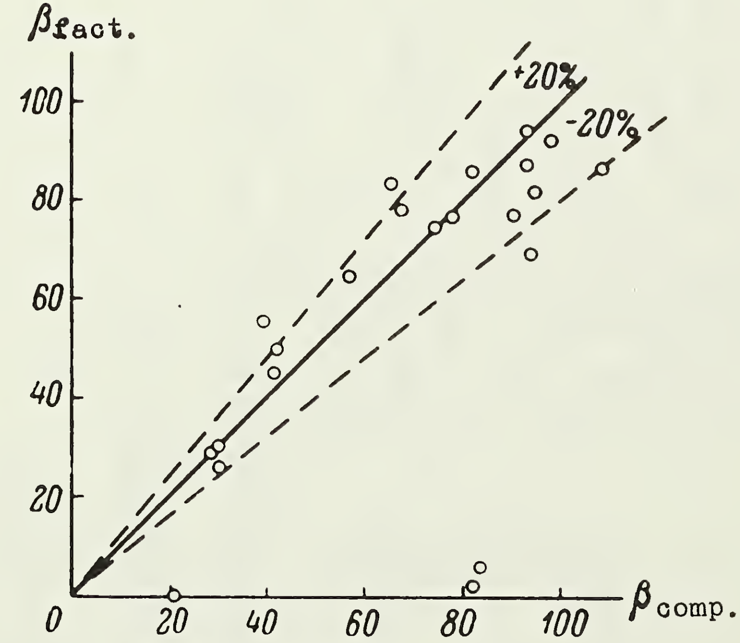

FIG. 3. FACTUAL VERSUS COMPUTED TRAP EFFICIENCY OF RESERVOIRS (β). WITH A CAPAC. COEFFICIENT $\alpha < 0.2$.
Dotted lines show the $\pm 20\%$ deviation of points from the line $\beta_{comp.} = \beta_{fact.}$

Formulas (7) and (8) make it possible to compute the time of silting of ponds when the nomogram shown in Figure 1 is not available and also when the mean annual turbidity does not correspond to the shown gradations of turbidity.

Formulas (7) and (8) were verified on 32 ponds of the Kursk Province. Computations of the relative annual volume of silting of ponds showed that the discrepancies between the actual and the computed value of C_{av} for 15 ponds (47% of the total number) do not exceed 5%, for 25 ponds they are less than 15% and for 31 less than 20%. A discrepancy greater than 20% occurred on one pond. This showed that the proposed graphical methods and the analytical expressions (7) and (8) can be fully utilized in the computation of the relative annual volume of silting of reservoirs and of the related time of silting of reservoirs on the territory of the CCP.

After the validity of the obtained formulas (7) and (8) was firmly confirmed by their verification on the Kursk ponds one can undertake the improvement of the expression for the computation of the trap efficiency of reservoirs. We shall do this by rewriting Expression (3) in the form:

$$\beta_{cp.} = \frac{C_{cp.}\alpha_0 \gamma}{\rho}. \tag{9}$$

We shall substitute in it the value C_{cp} from Formula (4) and will obtain the formula:

$$\beta_{cp.} = \frac{A\alpha_0 \gamma}{\alpha^n_{cp.}\rho}. \tag{10}$$

The parameters A and n as functions of turbidity are determined from the $n=f(\rho)$ and $A=f(\rho)$, curves shown in Fig. 2, or from Formulas (5) and (6).

For reservoirs where silting is less rapid and the difference between the initial and average capacity coefficients is small the trap efficiency can be computed with the approximate expression

$$\beta_{\text{cp.}} = \frac{A\gamma\alpha_{\text{cp.}}^{1-n}}{\rho}. \qquad (11)$$

Formula (11) was verified with data for 40 reservoirs given in Brune's (1953) paper. Regrettably, this paper does not show which capacity coefficient of reservoirs is given in it (initial or the average for the period of operation of the reservoir). We were therefore denied the opportunity to verify Formula (10). The computations showed that for reservoirs with a capacity coefficient $\alpha<0.2$ the discrepancies between the actual and computed values of trap efficiency do not, as a rule, exceed $\pm 20\%$ (Fig. 3). An exception are the data for the Williams and Holbert Reservoirs (3 points in the lower part of the graph) for which Brune's value of the mean annual volume of deposits is apparently too low. The scatter of points on the graph $\beta_{\text{comp.}}=f(\beta_{\text{fact.}})$ is due to the lack of data on the volume-weight of deposits for each reservoir (the computation was made for $\gamma=1000$ kg/m^3), and also to the above-mentioned ambiguity with respect to the capacity coefficient of the reservoirs which made it impossible to use the basic Formula (10).

For reservoirs with a capacity coefficient of $\alpha>0.2$, Formula (11) gives values that are, as a rule, too high and should not be used in such cases. Furthermore, on Brune's $\beta=f(\alpha)$ curve for $\alpha>0.2$ the trap efficiency of the reservoir varies only from 95 to 100% and can practically be taken to be $\beta=100\%$.

Expression (11) makes it possible therefore to compute with sufficient accuracy the trap efficiency of reservoirs with a capacity **coefficient** $\alpha<0.2$.

In conclusion we shall give an example of the computation of the time of silting of a pond using the graphical and analytical methods presented in this paper.

E x a m p l e o f c o m p u t a t i o n. Required to determine the time of silting of a pond on the Berezovaya Ravine (Kursk Province) to 60% of its initial volume.

The basic data are: mean annual water flow $Q=264\cdot10^3 m^3$, mean annual turbidity $\rho=5.13$ kg/m^3; initial volume of the pond $W_o=264\cdot10^3 m^3$.

1. The average capacity coefficient of the pond for the period of silting is:

$$\alpha_{cp.}=\frac{1}{2}(\alpha_0+\alpha_{fin.})=\frac{0.7W_0}{Q}=0.7.$$

2. From the relationship $C_{cp.}=f(\alpha_{cp.},\rho)$, given in Fig. 1, for $\rho=5.13$ kg/m^3 and $\beta=0.7$ the value of the relative annual volume of silting of the pond is $C_{av}=0.86\%$.

3. The average annual volume of silting is

$$R_0=C_{cp.}W_0=0.0086\cdot264\cdot10^3\ \text{м}^3=2.27\cdot10^3\ \text{м}^3.$$

4. And the time of silting of the volume equal to $0.6W_o$ is

$$T=\frac{0.6W_0}{R_0}=\frac{0.6\cdot264\cdot10^3\ \text{м}^3}{2.27\cdot10^3\ \text{м}^3}=70\ \textbf{years.}$$

We shall now make the same computations by the analytical method.

1. We shall compute the value of the relative annual volume of silting from Equation (4), having obtained parameters

A and n from the graph given in Fig. 2.

For ρ =5.13 kg/m^3, A=0.61, n=0.85.

$$C_{cp.} = \frac{A}{a^n_{cp.}} = \frac{0.61}{0.7^{0.85}} = 0.82\%.$$

2. The mean annual volume of silting is

$$R_0 = C_{cp.} W_0 = 0.0082 \cdot 264 \cdot 10^3 \text{ м}^3 = 2.17 \cdot 10^3 \text{ м}^3.$$

3. And the time of silting of the volume equal $0.6W_o$ is

$$T = \frac{0.6W_0}{R_0} = \frac{158 \cdot 10^3 \text{ м}^3}{2.17 \cdot 10^3 \text{ м}^3} = 73 \text{ years}$$

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A. F. KUDRYASHOV

THE BALANCE METHOD OF COMPUTING SEDIMENT FLOW AND ESTIMATING THE RATE OF SILTING OF RESERVOIRS

A quantitative evaluation of the sediment flow is necessary in the computation of the silting of reservoirs, of diversion structures, of irrigation canals, of navigation channels; of bank stabilization, etc. The channel process of each stream is closely related to the quantity of sediments transported by it and to the intra-annual distribution of sediment flow.

Depending on the modes of transport, river sediments are divided into suspended sediment and bedload. In this presentation we shall consider suspended sediments to be those which are caught by silt samplers in sampling suspended sediment. Bedload will be considered sediment which at the given instant forms the relief of the bottom of the investigated reach of the channel and is not being caught in sampling suspended sediment.

The ratio of suspended sediment to bedload depends on the nature of the hydrologic regime of the stream and on local physical-geographical factors. Published data on this ratio are not reliable and contradictory because there are not enough accurate measurements and also because these data are often based on unsupported theoretical considerations. It is therefore difficult at this stage to make any generalizations and recommendations about this ratio. This explains the need for mass observations of bedload and for a theoretical substantiation of its hydrodynamic transport.

Experience in the Use of the Balance Method of Estimating Sediment Flow

The accounting of bedload reduces in the main to the determination of its amount, its mechanical analysis, and

specific gravity. At the present time, few measurements of discharge of bedload are being made; because sufficiently accurate instruments and methods of investigation are lacking the obtained data are not reliable. Silt samplers of very different design have been and are being used in measuring bedload. But as was shown by long experience none of these devices give sufficiently dependable results.

With dune translocation of bedload its discharge can be estimated from the movement of the sand dunes. This method was utilized in the investigations on the Volga, Kama, Sheksna and Ob' and on other rivers (Lopatin, 1953). However, this method also does not fully meet the purpose. Investigations conducted in recent years make it possible to recommend the use of the balance method (Khachatryan, 1957; Karaushev, 1963). This method is applicable only in the presence of a reservoir in which the velocities of the current is considerably reduced.

The essence of the balance method of estimating bedload discharge is that the bedload and part of the suspended load which are settled out in the reservoir during the period between cleanings, washing out, or between regular surveys are systematically measured and the volume-weights of the deposits are determined. The suspended sediment above and below the reservoir is determined by periodic measurements of its discharge and by individual turbidity samples taken between such measurements. The application of this method is possible if during the period between cleaning or between regular surveys the bedload is not carried out of the reservoir. In this manner it is possible to determine the total amount of sediment carried by the river through the section located immediately above the reservoir or it can be determined analytically:

$$\sum S = \sum S_1 + \sum S_2 = \sum S_3 \pm \sum S_4 \qquad (1)$$

where Σ_S is the total sediment entering the reservoir, tons; ΣS_1 - suspended sediment inflow, tons; ΣS_2 - bedload inflow, tons; ΣS_3 - suspended sediment outflow, tons; and ΣS_4 - change ($\pm$) in the amount of sediment (suspended and bedload)deposited in the reservoir, tons.

The flow of bedload into the reservoir is determined from Equation (1) by:

$$\Sigma S_2 = \pm \Sigma S_4 + \Sigma S_3 - \Sigma S_1 \qquad (2)$$

All the items of Equation (2) can be measured directly. The time interval between measurements (every 10-15 days, once a month, etc.) determines the detail of bedload determinations (Kudryashov, 1961).

However, even the balance method of estimating the flow of bedload cannot be considered to be absolutely correct (Kudryashov, 1962) because when a reservoir is built the level of the erosion base in this section of the river changes. This change causes channel reformations in the reaches of the river above and below the reservoir. Such reformations apparently continue until an equilibrium profile is attained (Skryl'nikov, 1961) i.e., over several (3-5 and longer) years after the construction of the reservoir. For this reason, it would be inexpedient to apply the balance method of estimating bedload immediately after the construction of a reservoir since the calculation of the sediment deposited in the reservoir and of the inflow and outflow of suspended sediment will not fully represent the bedload of the river in the reach in which the structure is located. For instance, in case of a rise in the erosion base part of the bedload and of the suspended sediment will settle out in the reach of the river located considerably above the reservoir.

In principle the balance method of estimating bedload can be used for a storage volume of any size: a reservoir, pond, settling basin, etc. and also for different types of rivers, both plain and mountain.

To measure sediment flow by the balance method it is necessary to select suitable cases in which a more complete and accurate account of the volume of deposits can be made and with respect to the simplicity of the organization of the work. In selecting the object of investigation we were guided by the following considerations (Kudryashov, 1961, 1963):

a) In a case where there was a chain of reservoirs in the river the upper one was used.

b) In combating silting of reservoirs and in maintaining the required capacities operating organizations periodically remove the silt from the reservoir. The frequency and extent of these removals were determined beforehand for years with different flows. This procedure made it possible to set the dates and periods of observation of sediment flows.

c) During the period between silt removals the bedload must not enter into diversion canals or be discharged downstream because otherwise it would be impossible to estimate the amount of these sediments that is carried out of the reservoir.

d) The investigated reservoirs could have several incoming channels and several diversion canals. For instance, reservoirs designed to feed fishery ponds have 5-6 or more diversion canals. In selecting the reservoirs it is necessary to keep in mind that the greater the number of incoming channels and of diversion canals, the greater the volume of work required in computing the sediment flow by the balance method.

e) Settling basins of primitive design are of little use for this purpose because the structures are not dependable,

their dams are frequently washed out and water which seeps through the dam in large quantities carries with it part of the suspended sediment.

As an example of the application of the balance method in computing bedload we used the data of the State Hydrologic Institute for the Krasnopolyanskoe Reservoir on the Mzymta Rivers (Kudryashov, 1961, 1962).

To observe the flow of bedload into this reservoir main base lines were laid out. Survey profiles and gaging sections for measurement of suspended sediment and of water discharge; sites for sampling turbidity and bottom deposits, for the determination of volume-weights and mechanical analyses of deposits and for velocity measurements, etc. were established. The measurements were made from wooden and rubber boats and by wading. In addition to sampling the bottom deposits probes were used at each sampling point. Several staff gages were used to determine the elevation of the water surface.

Enough samples of bottom deposits were taken to characterize all types of grounds in the investigated reservoir. To determine the volume-weight of the bottom deposit which is needed to convert from volume to weight units, samples were taken in the most typical points along the width and length of the reservoir including whirlpool zones. The sampling was carried out with special devices: soil tubes, dredges, graduate cylinders, etc. The soil tubes, dredges and other devices were used where the depth exceeded 1 m.

During periods of drying of the reservoir (sluicing, repair of the equipment, etc.) the sampling was done with a metallic measuring cylinder 4 liters in volume made for this purpose. This volume was used to insure sufficient accuracy of determination of volume-weights of deposits consisting of particles not exceeding 5-7 cm in size.

The open side of the cylinder was placed on the bottom and was pushed into the deposit with the handles attached to the cover. The air in the cylinder escaped through a valve in the cover. After thecover of the cylinder reached the surface of the deposit the ground around the cylinder was dug out with a special spade which was used also to cover the open end of the cylinder. The cylinder was then inverted and was hung by the eyebolts affixed to its welt. The material was then cut off with the spade even with the edge of the cylinder. The valve in the cover was closed and the cylinder was immersed in water until the material was completely saturated. The cylinder with the saturated sample was weighed thus obtaining the weight of the saturated material from the difference between the weight of the cylinder with the sample and the weight of the empty cylinder. The sample was dried out to an air-dry state and weighed again. The difference between the weight of the sample in the saturated and air-dried states represented the weight of the water contained in the pores of the sample. The volume-weight was determined by dividing the weight in air-dry deposits by the volume of the cylinder. The specific gravity of the deposit was obtained by dividing the weight of the air-dry deposit by the difference between the volume of the cylinder and that of the pores.

Large pebbles and boulders in the deposit were measured directly in the field with tapes, scales, sieves, etc. The sampling dates of deposits were set in such a way as to reveal changes in volume-weights, densities and also in the mechanical analysis of deposits during the entire year; during the flood, in the recession of the flood, at the beginning and end of dry-weather flow, and at the rise of the flood.

The observations of changes in the hydrologic elements of the flow within the reservoir were made in accordance with the instructions of the Hydrometeorological Service. Surface velocities in the reservoir were measured with floats.

The deformations of the bottom and banks of the reservoir and the hydraulics of the flow in it were closely related to the hydrologic regime of the river and to the nature of water use. The sediment brought in by the river settled in the reservoir; the coarser sediments were deposited in its upper part and the finer particles settled out in the lower part where the velocity of the flow was considerably reduced. The silting of the reservoir was not uniform, there were layers of coarser deposits over finer ones and vice versa. Washing out of bottom deposits alternated with depositions.

The above-described processes are observed in reservoirs on both plain and mountain rivers.

The hydrologic regime of the Mzymta River is characterized by numerous floods. The river is fed by rainfall and by the melting snow on the southern slopes of the Great Caucasus mountain range. The river flows in rocky gorges. A narrow flood plain exists in a number of reaches. The catchment area of the reach above the AKH-TSU gorge is 798 km^2. The slope of the valley is 35.65 m/km. The average annual turbidity of the river is 248 g/m^3. Mean annual size of suspended sediment is 0.14 mm.

The reservoir of the Krasnopolyanskaya Hydroelectric Plant is located 2 km below the main Krasnaya Polyana gaging station. There are no tributaries in this reach of the river. This made it possible to consider the main gaging stations as the inflow section of the reservoir. The width of the river channel in the backwater is 70 m, the greatest width of the reservoir in its lower part is

115 m, the greatest depth at the gates in the dam is 6 m. Eighteen measuring sections, the spacing of which is shown in Table 1, were laid out along the length of the reservoir.

The distribution of the volume-weights of the bottom deposits in the Spring and in the fall is shown in Table 1. The volume-weight of the deposits reduces along the length of the reservoir irrespective of the time of the year; the greatest value of volume-weight is, as a rule, observed where the current is swiftest. The volume-weight ranges from 1.0 tons/m^3 to 2.1 tons/m^3, the smallest being typical of the loose ooze of organic deposits in the stagnant zone of the reservoirs at the dam where the velocity drops to 2-5 cm/sec. and the greatest - in the upper rocky reach of the river where it enters into the reservoir. The average volume-weight of bottom deposits for the entire reservoir is 1.8 tons/m^3.

The granulometric composition of bottom deposits in the reservoir of the Krasnopolyanskaya Hydroelectric Power Plant is partially depicted in Table 2. Like the volume-weight the size of the deposit reduces downstream. The smallest sizes of the deposits are found in the stagnant zone and at the dam where the velocities are small. Particles greater than 10 mm and particles from 2-0.2 mm predominate in the upper and lower parts of the reservoir respectively. The granulometric composition and the specific gravity of suspended sediment at the gaging sections of the reservoir shown in Table 3 below make it possible to compare the sizes of the suspended and bottom deposits. From this comparison it is clear that particles constituting some part of the bottom deposits in the reservoir are trapped in the suspended sediments which are carried out from the reservoir. Thus changes in the hydraulic conditions which are closely related to the hydrologic regime of the river and the mode of operation of the reservoir (water use) result in an exchange between sediment particles which are settled in the reservoir and those carried out from it.

T a b l e 1

DISTRIBUTION OF VOLUME-WEIGHTS OF BOTTOM DEPOSITS IN THE RESERVOIR OF THE KRASNOPOL'YANSKAYA HYDROELECTRIC POWER PLANT ON THE MZYMTA RIVER

Traverse numbers		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Average distance between traverses, m.			35	22.2	17.2	22.2	19.8	21.0	11.5	15.5	10.0	18.0	13.2	11.5	9.0	20.2	18.0	15.8	19.0	13.2
Volume-weight of deposits, T/m^3 (avg. along the traverse).	19 Sept. 1960.	1.3	1.3	1.35	1.1	1.7	1.8	1.8	1.8	2.0	1.9	2.0	2.0	1.9	1.9	1.9	2.0	2.0	1.8	2.0
	28 May, 1961.	—	1.5	1.2	1.2	1.5	1.7	1.8	1.8	1.6	1.6	1.6	1.6	2.0	2.0	1.7	1.8	1.9	—	—

R e m a r k. Section 18 is located in the upper part of the reservoir, Section 0 - at the gates in the dam. The spacing of the sections was determined by the shape of the reservoir taking into account the local topographic conditions.

Table 2

GRANULOMETRIC ANALYSIS (%) AND VOLUME-WEIGHT OF BOTTOM DEPOSITS OF THE MZYMTA RIVER IN THE RESERVOIR OF THE KRASNOPOL'YANSKAYA HYDROELECTRIC POWER PLANT RECORDED IN 1960

Date and place of sampling bottom deposits	Diameter of fractions, mm									Volume weight, T/m^3	Dimensions of stones (cm) on 1 m^2 of the bottom not included in the sample
	> 10	10–5	5–2	2–1	1–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.01		
7 July, middle of traverse 1.	—	1.2	2.8	10.0	12.2	54.7	13.4	2.4	3.3	1.20	None
7 July, middle of traverse 2.	—	2.0	13.8	45.8	27.1	9.1	1.1	0.1	1.0	1.14	»
7 July, traverse 4 at the right bank	—	3.8	32.2	42.0	15.8	5.2	0.2	0.3	0.5	1.51	»
4 July, middle of traverse 15.	57.1	17.6	12.9	7.2	3.6	1.3	0.08	0.07	0.15	2.14	12×5×7; 13×11×7; 15×11×7; 15×12×11; 7×5×1.5; 9×8×2; 5×4×1.5; 8×4×2; 5×3×2; 5×3×1; 8×4×2; 5×3×2; 5×3×1; 9×3×1; 2×1.5×0.8; 2×1.5×2.
2 July, middle of traverse 16.											
2 July, traverse 16 at the left bank	60.2	12.0	13.4	8.9	3.5	1.5	0.3	0.1	<0.05 0.1	2.10	43×25×20; 18×18×2; 15×15×5; 10×10×3; 3×3×3.
2 July, traverse 17 at the left bank	47.3	14.3	21.9	11.2	3.94	1.08	0.09	0.05	<0.05 0.14	—	15×10×7; 15×10×5; 20×22×15; 5×4×2; 5×3×2; 3×2×1.
2 July, traverse 17 in channel.	75.0	11.7	9.3	2.9	0.82	0.17	0.05	0.02	0.04	—	30×25×20; 6×7×3; 9×7×5; 5×3×1.5; 7×3.5×1.
2 July, traverse 17 in channel.	65.0	15.0	13.2	5.0	1.4	0.3	0.05	0.02	0.03	—	20×15×10; 7×6×5; 8×7×5; 5×4×2; 3×2×1; 2×1.5×0.7;
2 July, traverse 17 in channel.	96.4	2.7	0.7	0.1	<1 0.06	—	—	—	—	—	16×7×8; 6×4×5; 8×4×3; 5×2×1.5; 20×12×8; 27×20×9.
2 July, traverse 17 at the right bank	77.6	11.6	6.6	2.2	1.4	0.5	0.05	0.02	<0.05 0.03	—	7×5×4; 5×4×4; 6×4×3; 3×4×3.5; 5×2×3; 2×2×1.5.

Table 3

GRANULOMETRIC ANALYSIS (IN %) AND SPECIFIC GRAVITY OF SUSPENDED SEDIMENT OF THE MZYMTA RIVER ON THE HYDRO RANGES OF THE RESERVOIR RECORDED IN 1960.

Date and place of sampling suspended sediment	Diameter of fractions, mm								Average diameter mm	Specific gravity, T/m^3
	1—0.5	0.5—0.2	0.2—0.1	0.1—0.05	0.05—0.01	0.01—0.005	0.005—0.001	< 0.001		
6 July, main range	6.4	14.0	6.7	5.5	25.8	<0.01 41.6	—	—	0.1194	
6 July, stagnant zone of reservoir, traverse 6	—	—	—	—	32.8	22.7	34.5	10.0	0.01259	
6 July, at outflow through gates of dam	—	—	—	—	25.8	19.4	36.3	18.5	0.01048	
6 July, in diversion canal below settling basin	—	—	—	—	40.3	27.6	27.8	4.3	0.01505	2.77
28 July, main range	0.6	12.3	6.5	4.7	32.5	<0.01 43.4	—	—	0.07105	
28 July, stagnant zone of reservoir, traverse 6	—	0.01	0.4	1.6	25.2	16.0	42.8	14.0	0.01202	
28 July, at outflow through gates of the dam	—	0.05	0.4	3.3	39.2	12.7	35.2	9.0	0.0171	
28 July, in diversion canal below settling basin	—	0.1	1.5	4.0	33.6	19.0	32.8	9.0	0.0182	
24 August, main range	—	1.5	6.9	16.4	47.3	<0.01 27.9	—	—	0.04235	
24 August, stagnant zone of reservoir, traverse 6	—	—	—	—	29.1	21.2	37.7	12.0	0.01157	2.80
24 August, at outflow through gates of dam	—	0.1	3.7	5.3	36.5	17.2	29.2	8.0	0.0231	2.78
24 August, in diversion canal below settling basin	—	—	1.3	2.0	34.0	18.0	34.2	10.5	0.01613	
29 December, main range	0.9	10.3	8.4	13.1	<0.05 67.3	—	—	—	0.0928	
29 December, stagnant zone of reservoir, traverse 6	1.0	10.1	7.0	4.5	40.0	13.0	15.0	10.4	0.0714	
29 December, at outflow through gates of dam	—	1.6	2.5	1.5	38.5	20.5	26.4	9.0	0.0245	
29 December, in diversion canal below settling basin	—	3.8	3.8	6.2	48.5	20.0	10.5	7.2	0.0301	

Table 4

SEDIMENT FLOW AND AMOUNT OF DEPOSITION IN THE RESERVOIR AND SETTLING BASIN OF THE KRASNOPOL'YANSKAYA HYDROELECTRIC POWER PLANT ON THE MZYMTA RIVER RECORDED IN 1960

Date of reservoir survey	Periods between measurements, days	Amount of suspended sediment, T		Change in the amount of deposition in the reservoir		Average discharge of bed load (from balance) in the river	Water discharge fluctuations in the river during the observation period.
		Carried in	Carried out	Volume, m^3	Weight (from volume-weight), T		
Reservoirs							
9—13 VI—25—29 VI	16	2681.9	3250.9	+4205.25	+7820.7	6.0	44—73
25—29 VI— 7—10 VII	11.5	4054.0	3050.8	—1711.03	—3074.02	31.0	33—81
7—10 VII—25—27 VII	17.5	2913.3	2261.05	+535.07	+867.3	65.0	35—67
25—27 VII—16—19 VIII	22.5	31660.8	239258.94	—1017.85	—1703.8	106.0	21—72
16—19 VIII— 3— 9 IX	19.5	16874.4	31570.32	+4355.25	+7477.9	14.0	17—128
3— 9 IX—16—18 IX	11	1700.78	551.88	+3593.2	+5631.0	3.5	17—27
Settling Basins							
13 VI—29 VI	17	—	—	—57.46	—66.65		
29 VI— 6 VII	7	—	—	+184.2	+226.3		
6 VII—29 VII	23	—	—	—672.5	—845.2		
29 VII—28 VIII	29	—	—	+1138.5	+1238.7		
28 VIII—18 IX	21	—	—	—1044.0	—1196.5		

Remarks. (+) sign indicates deposition, (–) – erosion. In computing the average discharge of bed load by the balance method, the change in the amount of deposition in both the reservoir and the settling basin was taken into account.

The size of the suspended sediment (Table 3) in the reservoirs and in the outflow channels varies with the velocity of flow and with depths and also depends on the seasons of the year. As shown by observations the specific gravity of the suspended sediment remains almost unchanged.

The data on the flow of suspended sediment and on the quantity of deposits shown in Table 4 make it possible to determine with the balance method (Formula (2)) the average discharge of bedload in the inflow section of the reservoir during the period of record. The average discharge of the bedload of the river determined in this manner varied during this period from 3.5 kg/sec. to 106 kg/sec when the water discharge ranged from 17 to 128 m^3/sec., the bedload discharge being averaged for 11 to 22 days. In Table 5 are given discharges of bedload computed by the previously proposed formula of the author (Kudryashov, 1960).

$$r = 0.0075\gamma \frac{v^5}{g^2H} = 0.0075\gamma v H \left(\frac{v^2}{gH}\right)^2, \qquad (3)$$

where r is unit discharge of bedload by weight, g/cm per sec; γ - specific gravity of water, g/cm^3; g - acceleration of gravity, cm/sec^2; v - average velocity in the vertical, cm/sec; and H - average depth in the vertical, cm.

This formula (3) is derived from the dimensionless relationship between the weight concentration of bedload and Froude's number; the physical meaning of which is that each energy of the stream expressed by a Froude number corresponds to a very definite weight of bedload which the stream is capable to produce and to transport.

A comparison of the bedload discharges in the river determined by the balance method for the inflow section of the reservoir with those computed by Formula (3) for the main gaging section "Krasnaya Polyana" located in the reach without tributaries above the reservoir shows that

Table 5

DISTRIBUTION OF AVERAGE VELOCITIES, DEPTHS AND OF UNIT DISCHARGES OF BEDLOAD ALONG THE LENGTH OF THE GAGING SECTION "KRASNAYA POLYANA"

Date of measurement	Elements of flow	Numbers of velocity verticals										Measured water discharge in the river, m^3/sec.	Total bed load discharge in the river, kg/sec.
		1	2	3	4	5	6	7	8	9	10		
		Dist., fixed pt. on rt. bank to vel. verticals, m.											
		15	19	24	30	36	41	45	49	53	57		
24 VI	Average velocity in the vertical, cm/sec.	92	138	232	256	211	145	128	88	—	—	67.0	89.32
	Av. depth at the vertical, cm.	80	105	120	130	100	75	55	30	—	—		
	El. disch. bed load by equ. (3) g/cm per sec.	0.644	3.72	43.7	66.2	32.75	6.675	4.84	1.378	—	—		
6 VII	Average velocity in the vertical, cm/sec.	90	154	222	239	252	216	152	78	60	—	81.0	104.27
	Av. depth at the vertical, cm.	90	110	130	150	120	90	70	45	45	—		
	El. disch. bed load by equ. (3) g/cm per sec.	0.512	6.76	32.42	40.7	66.3	40.8	9.05	0.502	0.135	—		
23 VII	Average velocity in the vertical, cm/sec.	72	119	176	138	131	108	70	—	—	—	35.0	12.35
	Av. depth at the vertical, cm.	50	85	100	120	85	68	25	—	—	—		
	El. disch. bed load by equ. (3) g/cm per sec.	0.302	2.19	13.2	3.26	3.55	1.68	0.525	—	—	—		
20 VIII	Average velocity in the vertical, cm/sec.	49	83	150	122	82	104	35	—	—	—	19.0	6.086
	Av. depth at the vertical, cm.	50	70	100	90	60	50	20	—	—	—		
	El. disch. bed load by equ. (3) g/cm per sec.	0.044	0.442	5.925	2.345	0.482	1.90	0.02	—	—	—		
26 VIII	Average velocity in the vertical, cm/sec.	173	287	323	339	405	347	277	160	122	68	128.0	801.54
	Av. depth at the vertical, cm.	120	140	160	200	130	120	90	90	70	30		
	El. disch. bed load by equ. (3) g/cm per sec.	10.13	109.0	172.0	174.6	656.0	327.5	141.7	9.12	3.01	0.38		
23 IX	Average velocity in the vertical, cm/sec.	40	90	146	110	114	60	26	—	—	—	15.0	7.42
	Av. depth at the vertical, cm.	35	60	70	75	50	40	12	—	—	—		
	El. disch. bed load by equ. (3) g/cm per sec.	0.023	0.77	7.38	1.678	3.00	0.152	0.0078	—	—	—		

their values differ considerably. This difference is explained by the fact that the bedload discharges determined by the balance method were averaged for periods ranging from 11 to 22 days, while the hydrologic elements of the stream from which the bedload discharges were computed with Formula (3) were measured at the main gaging stations over a period of 1-2 hours. In the comparison we used the measurements of velocities and of depths in the vertical of the main gaging station for the period in 1960 for which bedload discharges obtained by the balance method are given in Table 4. To reveal the distribution of bedload discharges along the width of the channel for various velocities and depths in the verticals, values of unit bedload discharges computed with Formula (3) are given in Table 5.

Physical Meaning of the Lokhtin Number

The movement of bedload and of suspended sediment in the stream channel is accomplished by eddy formation. The eddies arise at the bottom of the stream under the action of the longitudinal velocity and of friction forces and are then propagated over the entire depth of the stream or over its lower part. The relatively fine particles of sediment are naturally kept in suspension by the energy of the eddies which move in the flowing stream. The transport of coarse sediments (bottom) is apparently accomplished by large vortices. It must be assumed that in this case the energy of the small eddies increases exponentially by some power m as they are combined into larger ones.

Considering the process of translocation of eddies in the stream to be a hydromechanical phenomenon (Kudryashov, 1962) the forces determining the behavior of the bottom and internal turbulent layers of the stream can be expressed by Boussinesq's number

$$Bu = \left(\frac{v_{\mathrm{e}}^2}{2gd} \right)^m \quad (4)$$

i.e., the ratio of the inertia forces to the forces of gravity. Here v_e is the characteristic velocity of the eddy formations (spiral movement), d - average diameter of the particles of the suspended sediment or of the bedload.

If the phenomenon is determined by forces of inertia and of gravity then with a steady regime, the constant ratio of inertia to gravity forces must hold for a given discharge of sediment R by weight, i.e.,

$$\frac{\left(\frac{v_e^2}{2gd}\right)^m}{R} = \text{const.} \qquad (5)$$

For bedload R can be expressed in tons per meter width of the channel per sec. or in tons/sec., for the suspended sediment - in tons/sec.

As applied to the water flow as a whole with a steady regime, the losses of specific energy of the stream I along the length of the considered reach must be constant for a given weight of water discharge, i.e.,

$$IQ = \text{const}, \qquad (6)$$

where Q - also can be expressed in tons/m/sec. or in tons/sec.; I - the losses of specific energy of the stream along the length of the reach, or the hydraulic gradient.

From Expressions (5) and (6) it can be concluded (Kudryashov, 1962) that under conditions of saturation of the stream with sediment and of a stable regime of the watercourse the constant ratio of inertia to gravity forces for eddy formations must for a given sediment discharge be inversely proportional to the losses of specific energy of the stream with corresponding water discharge.

$$\frac{\left(\frac{V_e^2}{2gd}\right)^m}{R} = \frac{a}{IQ}, \tag{7}$$

where a - coefficient, expressing the hydraulic conditions of sediment transport.

From this we have two ratios of the same dimensionality:

a) for bedload

$$\frac{d_{д.н.}^{m_1}{}^{*}}{I_{уч.}{}^{**}} = \frac{\left(\frac{V_{e_1}^2}{2g}\right)^{m_1}}{a_1 \frac{r}{q}} = \frac{A}{\frac{r}{q}}, \tag{8}$$

*bedload
**reach

where r/q is the weight concentration of bedload, A - dimensional coefficient;

b) for suspended sediment

$$\frac{d_{в.н.}^{m_2}{}^{*}}{I_{ср.}{}^{**}} = \frac{\left(\frac{V_{e_2}^2}{2g}\right)^{m_2}}{a_2 \frac{R}{Q}} = \frac{B}{\rho}, \tag{9}$$

*suspended load
**average

where R/Q = ρ is the turbidity of the water, B - a dimensional coefficient;

c) for mud flows Expression (7) can apparently be used without subdividing the sediment into bedload and suspended.

On the left side of the obtained Equations (8) and (9) are the Lokhtin (1897) coefficients which in the first case contain the average size of the bedload and in the second the average size of the suspended sediment. From the above it appears possible to conclude that indeed, as was maintained by V.M.Lokhtin, the stability of channels is expressed by the coefficient d/I, which as was shown, determines the weight concentration of bedload and of suspended sediment in the stream, their weight ratio, and hence, the erodibility

of channels and the erosion of the surface of the basin. It is also necessary to note that the size of the bedload expresses to some extent the channel process, and the size of the suspended sediment - the sum total of the water erosion processes which develop on the catchments under different natural conditions. In both the first and second cases the longitudinal hydraulic gradient reflect the transport conditions of the watercourse. A similar opinion was expressed back in 1952 by G.V.Lopatin (pages 236,328) in discussing the conditions of forming of suspended sediment flow: "the average turbidity of a river and the size of suspended sediment must in every instant of time correspond to the natural (including hydrologic) situation which exists in the given river basin at that instant. With this in mind we used the value of the size of the sediment composing the discharge of suspended sediment and the value of the average turbidity of the river as some indexes of the rate of water erosion within the specific catchment."

With Expressions (8) and (9) as a basis we shall discuss two examples of the effect of Man's economic activity on the stability of river channels, i.e., on the change in the value of the Lokhtin coefficient (Kudryashov, 1962).

E x a m p l e 1. The effect of the extent of cultivation or of afforestation on the change in the values of the elements entering into Formulas (8) and (9). With an increase of the plowed area the concentration of sediment in this particular case, turbidity, increases and the size of the sediment decreases. The afforestation of the surface of the basin causes a reduction in the concentration of sediment and an increase in the sediment size. The general hydraulic gradient of the river remains in both cases practically unchanged. The relationships (8) and (9) hold in both cases.

E x a m p l e 2. The effect of watering a locality by means of dams or of the lowering of the surface of the basin on the change in the parameters entering into Formulas (8) and (9). When a reach of the river is dammed up the hydraulic gradient and the concentration of sediments in the stream are reduced, the coarse sediment particles settle out. When the erosion base is washed out and the channel is deepened or when the surface of the basin is lowered then the slope, the size of the sediment particles, and the concentration of the sediment are changed. However, the relationship (8) and (9) will be correct also for these cases.

It follows from the above that relationships (8) and (9) can apparently be considered as characteristics of river channel stability and characteristics of the rate of the water erosion processes.

With the above-outlined theoretical substantiation an attempt was made to evaluate Expressions (8) and (9) quantitatively using published field and laboratory data. Figure 1 shows Equation (8) expressed quantitatively

*bedload
**reach

$$r = 39.6\gamma v H \left(\frac{\sqrt{d_{\text{д. н.}^{*}}}}{I_{\text{уч.}^{**}}} \right)^{-2} \qquad (10)$$

where r is unit discharge of bedload, g/cm/sec; γ - specific gravity of water, g/cm^3; v - average velocity in the vertical, cm/sec; H - average depth in the vertical, cm; $d_{\text{д. н.}}$ - mean diameter of bedload particles, cm; $I_{\text{уч.}}$ - hydraulic gradient of the reach of the stream; 39.6 - a constant dimensional coefficient, cm; $q = \gamma \cdot v \cdot H$ - unit discharge of water g/cm/sec.

The scatter of the points in Figure 1 is explained by the difference in the accuracy of measurements of the elements of the stream and of the sediment, the employed

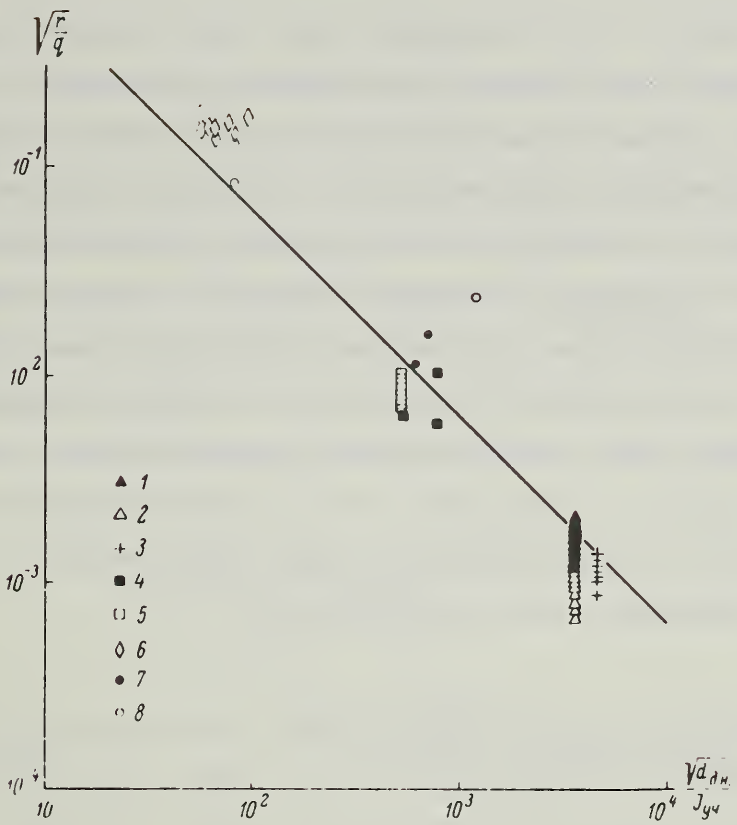

FIG. 1. Relation of Bedload in a Stream by Weight (r/q) to Lokhtin's Number $\left(\frac{\sqrt{d_{\text{д.н.}}}}{I_{\text{уч.}}}\right)$

1 - Volga Riv. at Uglich; 2 - Volga Riv. at Balobanovo; 3 - Mologa Riv. at Deli; 4 - Vychegda Riv. at Osievskiy; 5 - Kemka Riv. at Kharitonovka; 6 - Karan-Kul' Riv. gaging station; 7 - Missouri Riv. (after Vanoni); 8 - Vanoni's laboratory experiments.

methods and technique of measurements varied. For instance, in the investigations on the Karan-Kul' River (Umarov, 1961) the concentration of the bedload in the stream is somewhat too high because the storage capacity where part of the suspended sediment settled out was used in computing the sediment.

By comparing Formulas (3) and (10) we see that each of them includes the weight concentration of bedload. Two parameters, the Froude number and the Lokhtin number,

are related to a third. It follows that there must be a relationship between the Froude and Lokhtin numbers. The physical meaning of this relationship is that to every energy of the watercourse expressed by a Froude number there must correspond definite head losses (hydraulic gradient) which are expended by the stream in turbulent mixing and in the transport of bedload of the given size. The relationship between the Froude and Lokhtin numbers apparently determines the threshold of translocation of bedload. On the basis of analysis of a large number of field and laboratory investigations (see references) this relationship was obtained in the form of:

$$\frac{v^2}{gH} = 72.7 \left(\frac{\sqrt{d_{\text{д. н.}}}}{I_{\text{уч.}}} \right)^{-1}, \tag{11}$$

where 72.7 is a constant dimensional coefficient, $cm^{1/2}$ for the condition of translocation of bedloads; all the remaining elements entering Formula (11) are expressed in cm. and sec.

The structures of Formulas (3) and (11) makes it possible to transform them into the commonly used Chezy Formula for average velocity

$$v = 8.54 \frac{g^{1/2}}{d^{1/4}_{\text{д. н.}}} \sqrt{H I_{\text{уч.}}}, \tag{12}$$

where $C = 8.54\ g^{1/2}/d^{1/4}$ is a velocity coefficient, $cm^{1/2}/sec$; with 8.54 being in $cm^{1/4}$ (when the water temperature is 15° C) by the formula; $10\pi \sqrt[6]{\frac{\nu}{\sqrt{g}}}$. Likewise $C = \alpha_{\text{г}} \sqrt[4]{\frac{l_{\text{г}}}{d_{\text{д.н.}}}} \sqrt{g}$, where

$\alpha_{\text{г}}$ - shape coefficient of the dune, and $\ell_{\text{г}}$ - length of the dune.

Analyzing the data and Expression (11) it can be established that small Froude numbers and large Lokhtin numbers are satisfied by conditions in large and small rivers both with dune and duneless translocation of sediment with a tranquil regime of flow. Froude numbers greater than unity and small Lokhtin numbers correspond to conditions of anti-dune, bottom-dune and duneless translocation of sediment in a swift current.

Figure 2 expresses quantitatively the relationship

$$\rho = 56.5 \left(\frac{d_{\text{B. H.}}}{I_{\text{cp.}}} \right)^{-1/2}, \qquad (13)$$

according to long-term mean annual data from gaging stations at which turbidity and size of suspended sediment are measured. Here $\rho = R/Q$ is turbidity, g/m^3; $d_{B.H.}$ - average diameter of suspended sediment, mm; I_{cp} - average slope of the river from the source to the gaging stations, %o (m/km); 56.5 - a constant dimensional coefficient.

The performed verification of the accuracy of Formula (13) showed that for the rivers of the Volga Basin the coefficient of correlation is 0.88.

Estimating the Rate of Silting of Reservoirs

From the relationships (10) and (13) it follows that for a stabilized regime a definite relationship between the weight concentrations of bedload and of suspended sediment is maintained when the river is saturated with sediment. With this in mind and also analyzing the data of a series of field investigations (see references) it is possible to use Lokhtin's number as related to the sizes of bedload and suspended sediment in estimating the rate of silting of large and small reservoirs, settling basins, ponds, etc.

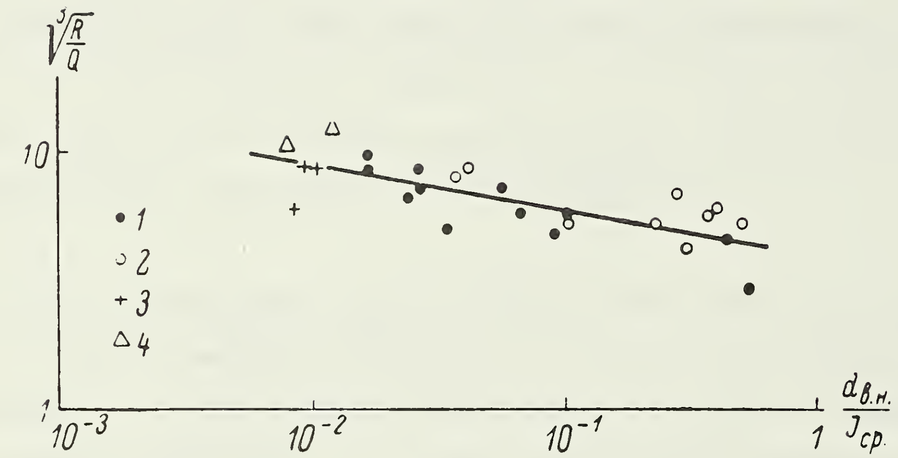

FIG. 2. Relation of the Weight Concentration of Suspended Sediment in the Stream (R/Q) to Lokhtin's Number

1 - rivers of the Volga Basin; 2 - Rivers flowing into the Black and Azov Seas; 3 - rivers of the Kuban' River Basin; 4 - rivers of Central Asia

The weight concentration of bedload and of suspended sediment in the river is naturally the principal factor affecting the rate of silting of reservoirs and ponds with the widest range in capacity coefficients (Prytkova, 1960) i.e., with different degrees of regulation of water flow W_o/Q, where W_o is the initial volume of the reservoir (of the pond) expressed in tons; Q - long-term average annual water flow in tons. Hence, for the same W_o/Q (Fig. 3)

$$R_o/W_o = A_o\ R/Q \tag{14}$$

where R_o is the mean annual weight of bedload and suspended sediment in the reservoir, tons; R - long-term average annual flow of suspended sediment, tons; A_o - a coefficient which depends on the degree of regulation of the water flow by the reservoir, for instance, for $W_o/Q = 1$ $A_o = 1$.

It is seen from Equation (14) that the rate of silting R_o/W_o is directly proportional to R/Q the weight concentration of suspended sediments in the river for reservoirs with the same degree of regulation of the water flow W_o/Q and is inversely proportional to R/Q for reservoirs with the same silting index W_o/R.

Expressions (3), (13) and (14) make it possible to assert that if two physical characteristics are related to a third, then there must be a relationship between them (Kudryashov, 1962) i.e., (Figure 4).

$$\frac{R_0}{W_0} = D\left(\frac{d_{\text{В. Н.}}}{I_{\text{ср.}}}\right)^m, \tag{15}$$

where D - a constant dimensional coefficient for the same W_o/Q, for instance, for $W_o/Q = 0.01$ $D = 0.0033$ $mm^{1/2}$ provided that $d_{B.H.}$ is in mm; W_o, Q, R_o in tons, m=-1/2, m is the exponent mentioned previously.

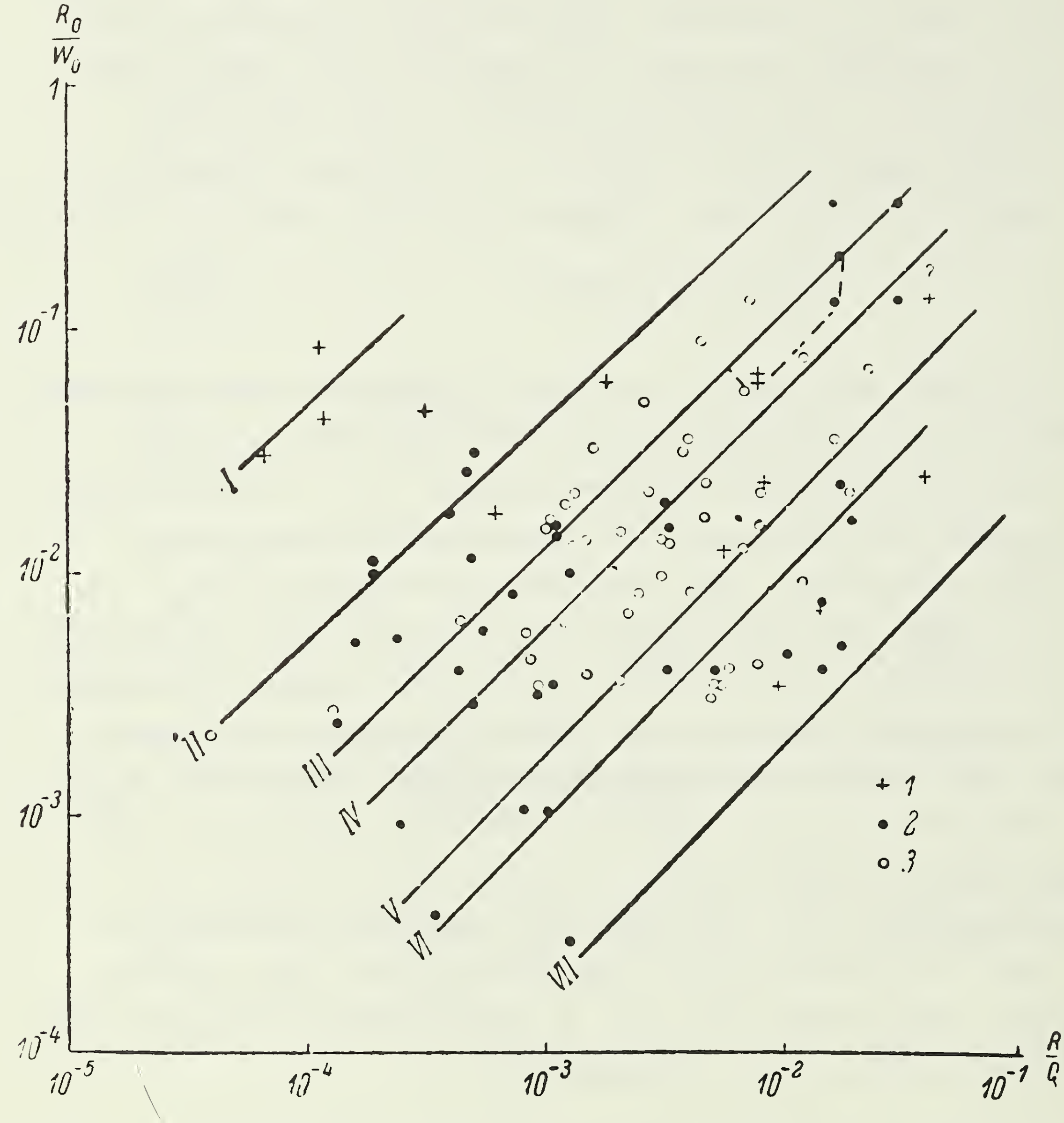

FIG. 3. RELATION OF THE RATE OF SILTING OF RESERVOIRS R_o/W_o TO THE WEIGHT CONCENTRATION OF SUSPENDED SEDIMENT IN THE STREAM (R/Q).

1 - Reservoirs of the USSR, USA, Germany (1936 boundaries), Switzerland, Italy, Algier (after Shamov); 2 - Reservoirs of the USA (after Brune); 3 - Ponds of the Ukr. SSR (according to GGI and IGG Acad. of Sci. Ukr. SSR). I - capacity coefficient of the reservoir = 0.001; II - 0.01; III - 0.05; IV - 0.1; V - 0.5; VI - 1.0; VII - 5.

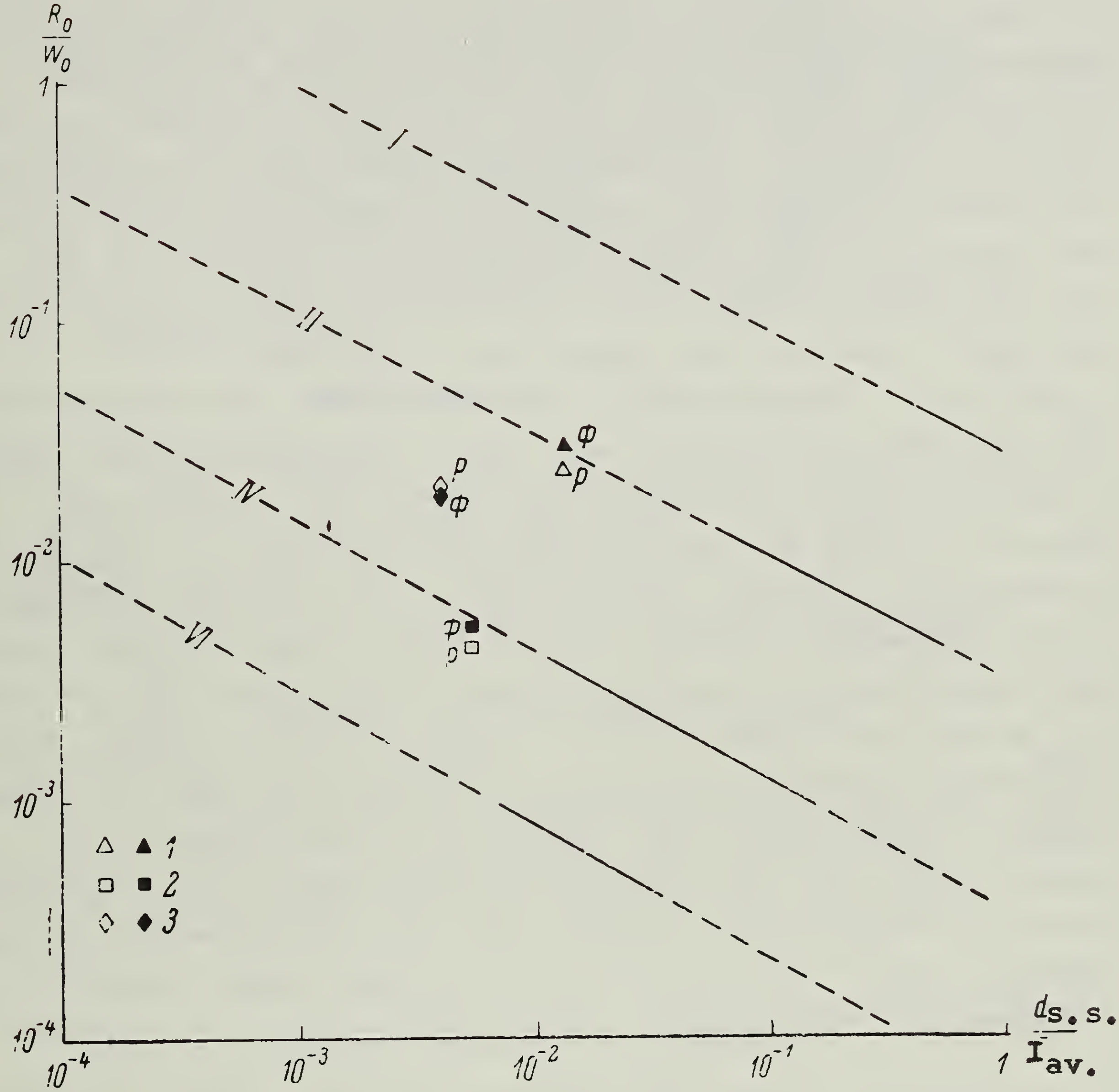

FIG. 4. VERIFICATION OF THE RELATION OF THE RATE OF SILTING OF RESERVOIRS (R_o/W_o) TO THE LOKHTIN NUMBER FOR SUSPENDED SEDIMENT ($d_{s.s.}/I_{av.}$).

1 - Farkhadskoe Reservoir; 2 - Kayrakumskoe Reservoir; 3 - Borshchenskoe Reservoir of the Kursk Province; Ф - factual, P - Computed. I, II, IV, VI - extent of regulation of water flow equal respectively to 0.001, 0.01, 0.1, 1.0.

A relationship between the rate of silting of reservoirs and Lokhtin's number for bedload can be obtained in a similar manner.

The correctness of Equation (15) was verified on the Farkhadskoe, Kayrakumskoe and Borshchenskoe Reservoirs. The results of the computations are shown in Figure 4. The rate of silting of the Farkhadskoe Reservoir as a function of Lokhtin's number was verified by records for many years. The initial volume of this reservoir, W_o=272 million m^3; the mean-annual water flow (Skryl'nikov, 1961), $Q=17.27 \cdot 10^3$ million ^{3}. Hence, the regulation of the water flow $W_o/Q=0.0158$. Zoporozhskaya Station of the Hydrometeorological Service (Town of Begovat) was used. Considering the length of the Syr-Daria River from the source of the Naryn to Begovat is 1000 km, and the drop in elevation is 6000 m, we obtain $I_{av.}$=0.006 (Il'in, 1959). The average diameter of the suspended sediment at the Zaporozhskaya gaging section was, according to long-term observations (from 1936 to 1944) $d_{s.s}$=0.083 mm (Shamov, 1951). Hence Lokhtin's number for suspended sediment is $d_{s.s}/I_{av.}$=0.0138. The rate of silting computed analytically and graphically with Figure 4 is equal 0.026. On the basis of observational data the actual rate of silting R_o/W_o=0.0306, with the volume-weight of ooze deposits equal 0.5 tons/m^3, and the mean annual weight of the deposits (Skryl'nikov, 1961) for 6 years of operation.

$$R_0 = \frac{100 \cdot 10^6 \cdot 0.5}{6} = 8.32 \cdot 10^6 \text{ т.}$$

Similarly with the data of SANIIRI, MOS, GIDEP of the Central Asian Expedition of GGI and other data the computed rate of silting of the Kayrakumskoe Reservoir was compared with the observed (Fig. 4). The comparison of the computed rate of silting of the Borshchenskoe Reservoir with the observed was made using the results of the investigations

carried out by the Laboratory of Limnology, Academy of Sciences USSR (Lopatin, 1961; Frolov, 1961). In this manner the rate of silting of two large and one small reservoir was estimated with sufficient accuracy.

On the basis of the above-presented considerations and of analysis of field data it must be concluded that with Lokhtin's number related to the sizes of bedload and of suspended sediment of a stream it is possible to estimate the rate of silting, of both large and small reservoirs with different degrees of regulation of the water- and sediment flows.

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